

# HYPERON SPECTROSCOPY WITH A $K_L$ BEAM

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- ▶ Missing Resonances
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- ▶ Current Data
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# Quark Shell Model for Baryons

It is convenient to describe baryons with a "quark shell model" in which each quark moves in a mean field generated mainly by the gluons in the hadron. Lattice QCD calculations have shown that the predicted spectrum of excited states is *not arbitrary*; instead it is more-or-less consistent with what is expected from SU(6) symmetry.

In such models, baryons are grouped into three possible SU(6) multiplets:

$$\begin{aligned} \mathbf{56}_S &= {}^2\mathbf{8} + {}^4\mathbf{10} \\ \mathbf{70}_M &= {}^2\mathbf{8} + {}^4\mathbf{8} + {}^2\mathbf{10} + {}^2\mathbf{1} \\ \mathbf{20}_A &= {}^2\mathbf{8} + {}^4\mathbf{1} \end{aligned}$$

# SU(6) Multiplets in the Harmonic-Oscillator Model for Baryons\*

$$N = 0 \quad \psi(\mathbf{56}, 0^+) = (1s)^3$$

$$N = 1 \quad \psi(\mathbf{70}, 1^-) = (1s)^2(1p)$$

$$N = 2 \quad \psi(\mathbf{56}, 0^+) = \sqrt{\frac{2}{3}}(1s)^2(2s) + \sqrt{\frac{1}{3}}(1s)(1p)^2$$

$$\psi(\mathbf{70}, 0^+) = \sqrt{\frac{1}{3}}(1s)^2(2s) + \sqrt{\frac{2}{3}}(1s)(1p)^2$$

$$\psi(\mathbf{56}, 2^+) = \sqrt{\frac{2}{3}}(1s)^2(1d) - \sqrt{\frac{1}{3}}(1s)(1p)^2$$

$$\psi(\mathbf{70}, 2^+) = \sqrt{\frac{1}{3}}(1s)^2(1d) - \sqrt{\frac{2}{3}}(1s)(1p)^2$$

$$\psi(\mathbf{20}, 1^+) = (1s)(1p)^2$$

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\*D. Faiman and A.W. Hendry, PRD **173**, 1720 (1968).

# N=3 Baryons

The eight SU(6) multiplets that are allowed in the  $N = 3$  band are:

$$\begin{array}{lll} (\mathbf{56}, 1^-) & (\mathbf{70}, 2^-) & (\mathbf{56}, 3^-) \\ (\mathbf{70}, 1^-) & & (\mathbf{70}, 3^-) \\ (\mathbf{70}, 1^-) & & (\mathbf{20}, 3^-) \\ (\mathbf{20}, 1^-) & & \end{array}$$

and the allowed shell-model configurations are:

$$\begin{array}{ll} (1s)^2(2p) & L = 1 \\ (1s)^2(1f) & L = 3 \\ \hline (1s)(1p)(2s) & L = 1 \\ (1s)(1p)(1d) & L = 1, 2, 3 \\ \hline (1p)^3 & L = 1, 3 \end{array}$$

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- ▶ Pure hyperon states in the  $N = 2$  ( $\mathbf{20}, 1^+$ ) multiplet cannot couple to  $\bar{K}N$  via a single-quark transition operator. They will not be considered further.
- ▶ Pure hyperon states in the  $N = 3$  ( $\mathbf{20}, 1^-$ ), ( $\mathbf{70}, 2^-$ ), and ( $\mathbf{20}, 3^-$ ) multiplets cannot couple to  $\bar{K}N$  via a single-quark transition operator. They will not be considered further.
- ▶ The next several slides compare experimental observations with predictions for low-lying states in the other multiplets (not including  $N = 3$ )

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# $N=0$ ( $56,0^+$ ) Ground-State Baryons

$^2_8$	$N(939)$	****
$1/2^+$	$\Lambda(1116)$	****
	$\Sigma(1193)$	****
	$\Xi(1322)$	****
$^4_{10}$	$\Delta(1232)$	****
$3/2^+$	$\Sigma(1385)$	****
	$\Xi(1530)$	****
	$\Omega(1672)$	****

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# $N=1$ ( $70, 1^-$ ) Negative-Parity Excited States

$^2 8$	$N(1535)$	****	
$1/2^-$	$\Lambda(1670)$	****	
	$\Sigma(1620)$	*	
	$\Xi(1690)$	***	spin-parity undetermined

$^2 8$	$N(1520)$	****	
$3/2^-$	$\Lambda(1690)$	****	
	$\Sigma(1670)$	****	
	$\Xi(1820)$	***	

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# $N=1$ ( $70, 1^-$ ) Negative-Parity Excited States

$4_8$	$N(1650)$	****	
$1/2^-$	$\Lambda(1800)$	***	
	$\Sigma(1750)$	***	
	$\Xi(1950)$	***	spin-parity undetermined

$4_8$	$N(1700)$	***	
$3/2^-$	$\Lambda$		
	$\Sigma$		
	$\Xi$		

$4_8$	$N(1675)$	****	
$5/2^-$	$\Lambda(1830)$	****	
	$\Sigma(1775)$	****	
	$\Xi(2030)$	***	spin-parity undetermined

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# N=1 ( $70, 1^-$ ) Negative-Parity Excited States

$^2 10$	$\Delta(1620)$	****	$^2 1$	$\Lambda(1405)$	****
$1/2^-$	$\Sigma$		$1/2^-$		
	$\Xi$				
	$\Omega$				

$^2 10$	$\Delta(1700)$	****	$^2 1$	$\Lambda(1520)$	****
$3/2^-$	$\Sigma(1940)$	***	$3/2^-$		
	$\Xi$				
	$\Omega$				

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# N=2 (**56,0<sup>+</sup>**) Positive-Parity Excited States

$^2_8$	$N(1440)$	****
$1/2^+$	$\Lambda(1600)$	***
	$\Sigma(1660)$	***
	$\Xi$	

$^4_{10}$	$\Delta(1600)$	***
$3/2^+$	$\Sigma$	
	$\Xi$	
	$\Omega$	

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# $N=2$ ( $56, 2^+$ ) Positive-Parity Excited States

$2_8$	$N(1720)$	****
$3/2^+$	$\Lambda(1890)$	****
	$\Sigma$	
	$\Xi$	

$2_8$	$N(1680)$	****
$5/2^+$	$\Lambda(1820)$	****
	$\Sigma(1915)$	****
	$\Xi$	

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# N=2 (56,2<sup>+</sup>) Positive-Parity Excited States

$^4_{10}$	$\Delta(1910)$	****	$^4_{10}$	$\Delta(1920)$	***
$1/2^+$	$\Sigma$		$3/2^+$	$\Sigma$	
	$\Xi$			$\Xi$	
	$\Omega$			$\Omega$	

$^4_{10}$	$\Delta(1905)$	***	$^4_{10}$	$\Delta(1950)$	****
$5/2^+$	$\Sigma$		$7/2^+$	$\Sigma(2030)$	****
	$\Xi$			$\Xi$	
	$\Omega$			$\Omega$	

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# N=2 (70,0<sup>+</sup>) Positive-Parity Excited States

$2_8$	$N(1710)$	***	$4_8$	$N$	
$1/2^+$	$\Lambda(1810)$	***	$3/2^+$	$\Lambda$	
	$\Sigma(1880)$	**		$\Sigma$	
	$\Xi$			$\Xi$	
$2_{10}$	$\Delta(1750)$	*	$2_1$	$\Lambda(1710)$	*
$1/2^+$	$\Sigma$		$1/2^+$		
	$\Xi$				
	$\Omega$				

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# N=2 (70,2<sup>+</sup>) Positive-Parity Excited States

$^4_8$	$N(1880)$	**	$^4_8$	$N(1900)$	***
$1/2^+$	$\Lambda$		$3/2^+$	$\Lambda$	
	$\Sigma$			$\Sigma$	
	$\Xi$			$\Xi$	

$^4_8$	$N(2000)$	**	$^4_8$	$N(1990)$	**
$5/2^+$	$\Lambda$		$7/2^+$	$\Lambda(2020)$	*
	$\Sigma$			$\Sigma$	
	$\Xi$			$\Xi$	

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# $N=2$ ( $70, 2^+$ ) Positive-Parity Excited States

$^2_8$	$N$	$^2_8$	$N(1860)$	**
$3/2^+$	$\Lambda$	$5/2^+$	$\Lambda$	
	$\Sigma$		$\Sigma$	
	$\Xi$		$\Xi$	

$^2_{10}$	$\Delta$	$^2_{10}$	$\Delta(2000)$	**
$3/2^+$	$\Sigma$	$5/2^+$	$\Sigma$	
	$\Xi$		$\Xi$	
	$\Omega$		$\Omega$	

$^2_1$	$\Lambda$	$^2_1$	$\Lambda(2110)$	***
$3/2^+$		$5/2^+$		

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# Summary of Missing Resonances

(one-star states are included as "missing")

	$N = 0$	$N = 1$	$N = 2$
$N$	0	0	2
$\Delta$	0	0	2
$\Lambda$	0	1	9
$\Sigma$	0	3	15
$\Xi$	0	3	19
$\Omega$	0	2	8

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

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

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

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  $\theta$ .

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# 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  $J = l - \frac{1}{2}$ .

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# Isospin Amplitudes

- ▶ We may ignore small CP-violating terms and write

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

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

- ▶ We have both  $I = 0$  and  $I = 1$  amplitudes for  $KN$  and  $\bar{K}N$  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-Gordan coefficients.

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# Isospin Amplitudes (cont'd)

$$T(K_L^0 p \rightarrow K_S^0 p) = \frac{1}{2} \left( \frac{1}{2} T^1(KN \rightarrow KN) + \frac{1}{2} T^0(KN \rightarrow KN) \right)$$

$$- \frac{1}{2} T^1(\bar{K}N \rightarrow \bar{K}N)$$

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

$$T(K_L^0 p \rightarrow \pi^+ \Sigma^0) = -\frac{1}{2} T^1(\bar{K}N \rightarrow \pi \Sigma)$$

$$T(K_L^0 p \rightarrow \pi^0 \Sigma^+) = \frac{1}{2} T^1(\bar{K}N \rightarrow \pi \Sigma)$$

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

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- ▶ Only  $\Sigma^*$  resonances are formed as intermediate states in  $K_L^0 p$  reactions.
- ▶ The inelastic 2-body reactions that can be studied with a  $K_L^0$  beam would be good probes for finding missing  $\Sigma^*$  states due to isospin selectivity, absence of nonresonant  $KN$  background, and fact that their amplitudes only involve  $\bar{K}N$  coupling in initial state.
- ▶ Formalism exists to do PWAs of these reactions and to extract resonance parameters, including *pole positions*.

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- ▶ To search for missing  $\Sigma^*$  states that couple weakly to  $\bar{K}N$ , use production reactions such as  $K_L^0 p \rightarrow \pi^+ \Sigma^{0*}$ , with  $\Sigma^{0*} \rightarrow \pi^0 \Lambda$ , or use  $K_L^0 p \rightarrow \pi^0 \Sigma^{+*}$ , with  $\Sigma^{+*} \rightarrow \pi^+ \Lambda$ . (Note that the  $\pi \Lambda$  decays establish  $\Sigma^*$  states ( $I = 1$ ) uniquely.)
- ▶ To search for missing  $\Lambda^*$  states that couple weakly to  $\bar{K}N$ , use production reactions such as  $K_L^0 p \rightarrow \pi^+ \Lambda^*$ , with  $\Lambda^* \rightarrow \pi^+ \Sigma^-$ ,  $\Lambda^* \rightarrow \pi^- \Sigma^+$ , or  $\Lambda^* \rightarrow \pi^0 \Sigma^0$ . (Note that the  $\pi^0 \Sigma^0$  decays establish  $\Lambda^*$  states ( $I = 0$ ) uniquely.)
- ▶ To search for missing  $\Xi^*$  or  $\Omega^*$  states, use production reactions such as  $K_L^0 N \rightarrow K \Xi^*$ ,  $K_L^0 N \rightarrow \pi K \Xi^*$ , and  $K_L^0 N \rightarrow KK \Omega^*$ .

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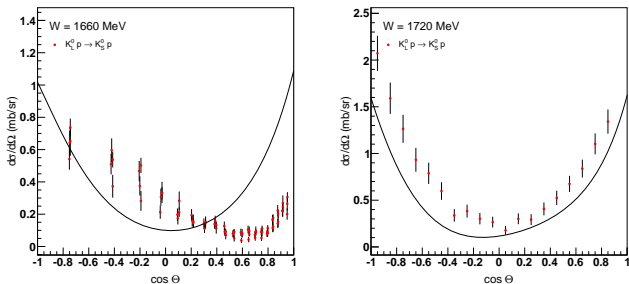
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# Why We Have to Measure Cascades at JLab

- ▶ Heavy-quark symmetry suggests that multiplet splittings in strange, charm, and bottom hyperons should approximately scale as inverses of corresponding quark masses:  $1/m_s : 1/m_c : 1/m_b$ .
- ▶ Any observed scaling failure implies that structures of corresponding states are *anomalous* and *very different* from one another.
- ▶ So far, this scaling has only been tested in the lowest negative-parity multiplet:  $\Lambda(1405)\frac{1}{2}^- - \Lambda(1520)\frac{3}{2}^-$ ,  $\Lambda_c(2595)\frac{1}{2}^- - \Lambda_c(2625)\frac{3}{2}^-$ ,  $\Lambda_b(5912)\frac{1}{2}^- - \Lambda_b(5920)\frac{3}{2}^-$ .
- ▶ It works approximately (30%) well for those splittings. It should work even better for  $\Xi$ ,  $\Xi_c$ ,  $\Xi_b$  splittings, and should be very good for  $\Omega$ ,  $\Omega_c$ ,  $\Omega_b$  splittings.
- ▶ We could measure the Cascade spectrum at JLab as LHCb is doing for charmed Cascades:  $\Xi_c(2790)\frac{1}{2}^- - \Xi_c(2815)\frac{3}{2}^-$ .



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



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

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- ▶  $K^- p \rightarrow \pi^0 \Lambda$  and  $K_L^0 p \rightarrow \pi^+ \Lambda$  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.
- ▶ 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.

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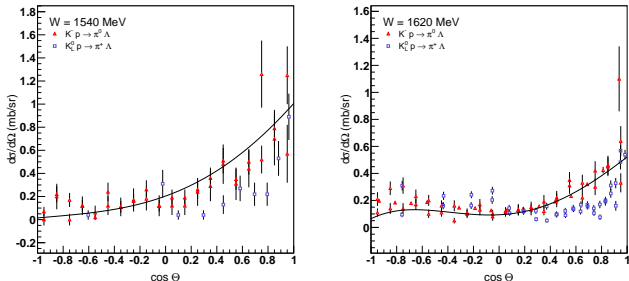
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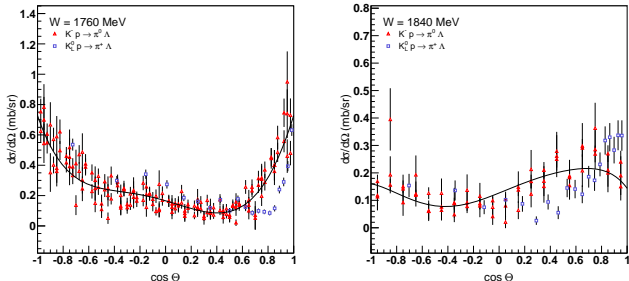
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# $d\sigma/d\Omega$ Data for $K^-p \rightarrow \pi^0\Lambda$ and $K_L^0p \rightarrow \pi^+\Lambda$



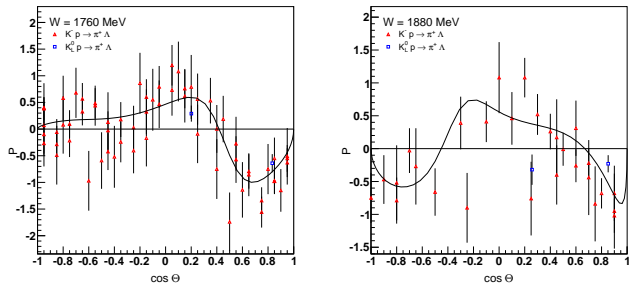
**Figure:** Comparison of selected  $d\sigma/d\Omega$  data for  $K^-p \rightarrow \pi^0\Lambda$  (red) and  $K_L^0p \rightarrow \pi^+\Lambda$  (blue) at 1540 MeV and 1620 MeV. The curves are from our previous PWA of  $K^-p \rightarrow \pi^0\Lambda$  data.

# $d\sigma/d\Omega$ Data for $K^-p \rightarrow \pi^0\Lambda$ and $K_L^0p \rightarrow \pi^+\Lambda$



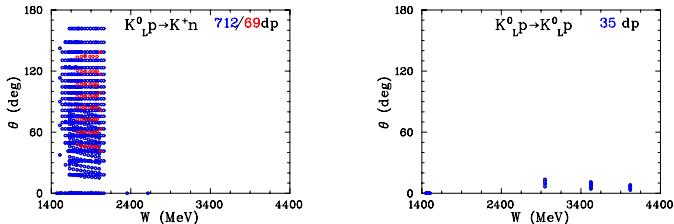
**Figure:** Comparison of selected  $d\sigma/d\Omega$  data for  $K^-p \rightarrow \pi^0\Lambda$  (red) and  $K_L^0p \rightarrow \pi^+\Lambda$  (blue) at 1760 MeV and 1840 MeV. The curves are from our previous PWA of  $K^-p \rightarrow \pi^0\Lambda$  data.

# Polarization Data for $K^-p \rightarrow \pi^0\Lambda$ and $K_L^0p \rightarrow \pi^+\Lambda$



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

# Overview of Experimental Database



**Figure:** Experimental data available for  $K_L^0 p \rightarrow K^+ n$  and  $K_L^0 p \rightarrow K_L^0 p$  as a function of c.m. energy  $W$ . The number of data points (dp) is given in the RHS of each subplot; blue (red) shows amount of unpolarized (polarized) observables. Total cross sections are plotted at  $0^\circ$ .

# Overview of Experimental Database (Cont'd)

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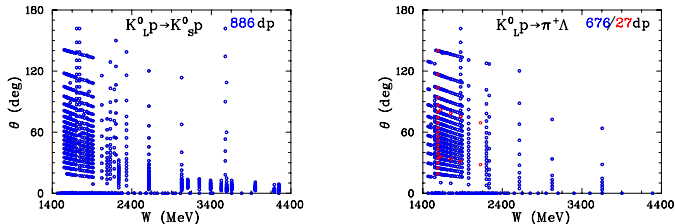
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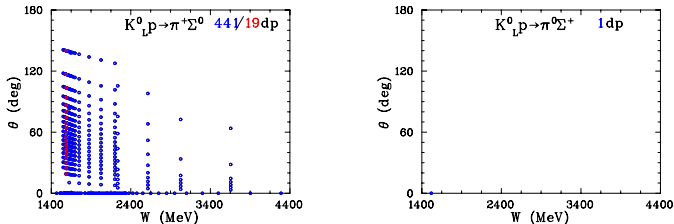
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**Figure:** Experimental data available for  $K_L^0 p \rightarrow K_S^0 p$  and  $K_L^0 p \rightarrow \pi^+ \Lambda$  as a function of c.m. energy  $W$ . The number of data points (dp) is given in the RHS of each subplot; blue (red) shows amount of unpolarized (polarized) observables. Total cross sections are plotted at  $0^\circ$ .

# Overview of Experimental Database (Cont'd)



**Figure:** Experimental data available for  $K_L^0 p \rightarrow \pi^+ \Sigma^0$  and  $K_L^0 p \rightarrow \pi^0 \Sigma^+$  as a function of c.m. energy  $W$ . The number of data points (dp) is given in the RHS of each subplot; blue (red) shows amount of unpolarized (polarized) observables. Total cross sections are plotted at  $0^\circ$ .



- ▶ Reactions  $K_L^0 p \rightarrow \pi^+ \Sigma^0$  and  $K_L^0 p \rightarrow \pi^0 \Sigma^+$  are **isospin selective** (only  $I = 1$  amplitudes are involved) whereas reactions  $K^- p \rightarrow \pi^- \Sigma^+$  and  $K^- p \rightarrow \pi^+ \Sigma^-$  are not. **New  $K_L^0 p$  measurements would lead to better understanding of  $\Sigma^*$  states and help constrain amplitudes for  $K^- p \rightarrow \pi \Sigma$  reactions.**

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# Discussion: The Need for $K_L n$ Measurements

- ▶ Similarly,  $K_L^0 n$  measurements, combined with  $K_L^0 p$  data, would improve our knowledge of  $\Lambda^*$  states. **The existing  $K_L^0 n$  database is nonexistent.**
- ▶ Scattering the  $K_L$  beam on a "neutron" target would yield a new and strongly desired source of experimental data to pinpoint the properties of the  $\bar{K}N$  amplitude. Predictions for  $K_L n$  scattering to various 2-body final states ( $K^- p$ ,  $\bar{K}^0 n$ ,  $\pi^0 \Lambda$ ,  $\pi^0 \Sigma^0$ ,  $\pi^+ \Sigma^-$ ,  $\pi^- \Sigma^+$ ) could be used to distinguish between different model predictions for  $d\sigma/d\Omega$  and  $Pd\sigma/d\Omega$ .
- ▶  $K_L n$  data are also much needed to study the  $K^+ \Xi^-$  and  $K^0 \Xi^0$  final states. Corresponding  $K^- p$  data are extremely sparse for  $K \Xi$  final states.

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# Discussion: More on $K\Xi$ Final States

- ▶ Threshold for  $K^-p$ ,  $K_L^0p$ , and  $K_L^0n$  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  $K_L^0p \rightarrow K^+\Xi^0$  and very few (none recent) for  $K^-p \rightarrow K^0\Xi^0$  or  $K^-p \rightarrow K^+\Xi^-$
- ▶ Measurements for these reactions would be very helpful, especially for comparing with predictions from dynamical coupled-channel (DCC) models
- ▶  $K_L^0p \rightarrow K^+\Xi^0$  is isospin-1 selective, whereas the reactions  $K^-p \rightarrow K^0\Xi^0$  and  $K^-p \rightarrow K^+\Xi^-$  involve both  $I = 0$  and  $I = 1$  amplitudes

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# Expected $K_{LP} \rightarrow K_{SP}$ Results

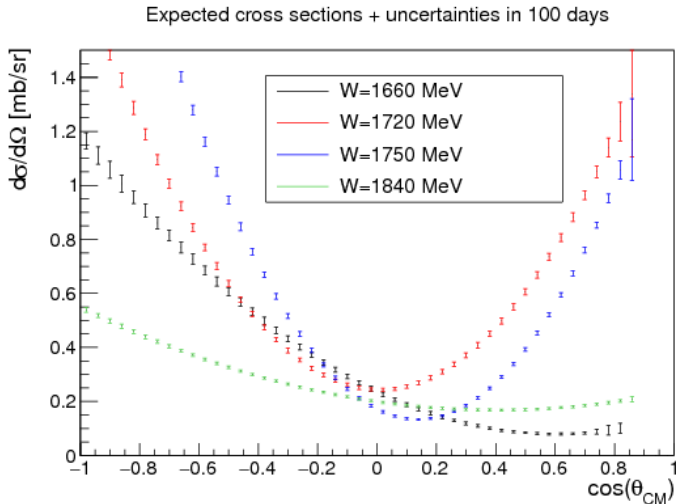


Figure: Reconstructed  $K_{LP} \rightarrow K_{SP}$   $d\sigma/d\Omega$  values for various values of  $W$  for 100 days of running.

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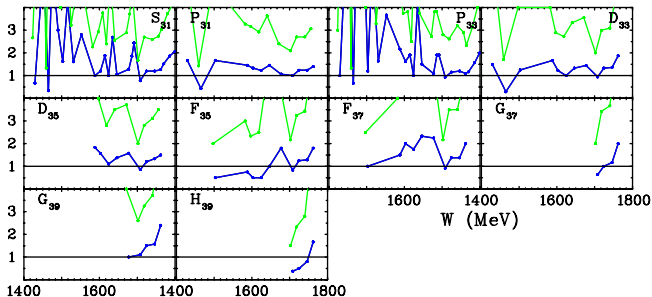
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# Ratios of Uncertainties in PW Amplitudes



**Figure:** Ratios of uncertainties of single-energy PW amplitudes of proposed data for 20 days (green) and 100 days (blue) of running based on analogous PWA of  $\pi^+p \rightarrow \pi^+p$  vs. single-energy solutions associated with SAID WI14 solution (a fit of the world database).

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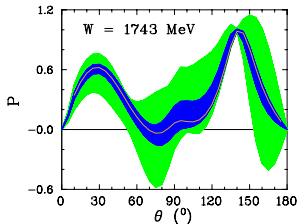
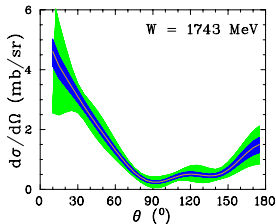
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# Impact of Proposed Data on SAID SES



**Figure:** Two examples ( $W = 1743$  MeV) showing impact of proposed data on SAID single-energy solutions. The green band indicates expected uncertainties for 20 days and the blue band for 100 days of running. The solid curve corresponds to the SAID W114 solution.

# Expected Precision of Resonance Parameters

Resonance	PDG2016		SAID		20 days		100 days	
	$M$ (MeV)	$\Gamma$ (MeV)	$M$ (MeV)	$\Gamma$ (MeV)	$M$ (MeV)	$\Gamma$ (MeV)	$M$ (MeV)	$\Gamma$ (MeV)
$\Delta(1620)1/2^-$	$1630\pm 30$	$140\pm 10$	$1615.2\pm 0.4$	$146.9\pm 1.9$	$1614\pm 4$	$140\pm 20$	$1615\pm 1$	$130\pm 5$
$\Delta(1700)3/2^-$	$1700\pm 40$	$300\pm 100$	$1695.0\pm 1.3$	$375.5\pm 7.0$	$1720\pm 60$	$580\pm 350$	$1714\pm 20$	$530\pm 100$

**Figure:**  $S_{31}(1620)$  and  $D_{33}(1700)$  Breit-Wigner parameters from PDG 2016 and SAID WI14 compared with corresponding values expected for 20 and 100 days of running time.

# Summary and Conclusions

- ▶ New data for inelastic  $K_L^0 p$  scattering would greatly improve our knowledge of  $\Sigma^*$  resonances. Measurements on a neutron target would similarly improve our knowledge of  $\Lambda^*$  resonances.
- ▶ Very few polarization data are available for any  $K_L^0 p$  reactions but are needed to help remove ambiguities in PWAs.
- ▶ To search for missing hyperon resonances, we will carry out measurements of production reactions using both hydrogen and deuterium targets:
  - $\Sigma^*$ :  $K_L^0 N \rightarrow \pi \Sigma^* \rightarrow \pi \pi \Lambda$
  - $\Lambda^*$ :  $K_L^0 N \rightarrow \pi \Lambda^* \rightarrow \pi \pi \Sigma$
  - $\Xi^*$ :  $K_L^0 N \rightarrow K \Xi^*, \pi K \Xi^*$
  - $\Omega^*$ :  $K_L^0 N \rightarrow K K \Omega^*$
- ▶ Measurements with  $K_L^0$  beams performed with good energy & angle coverage & good statistics would likely find several missing hyperon resonances.

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## Summary and Conclusions (Cont'd)

- ▶ With 100 days of running time with a hydrogen target *plus* 100 days with a deuterium target, we can provide reliable solution for all resonances having elastic branching ratios larger than 4%, at least up to  $\ell = 4$ . With 20 days of beamtime for each target, we could only carry out simple "bump hunting".
- ▶ From our  $\pi^+p$  PWA study, we can conclude that the precision of resonance parameters extracted from PWAs of KLF data for the higher-mass  $\Lambda^*$  and  $\Sigma^*$  states that we propose to measure will deteriorate w/o sufficient running time. The spectrum of these states is expected to be densely populated with typical mass differences of about 100 MeV for states with the same quantum numbers; therefore, 100 days of beam time with each target (hydrogen and deuterium) is needed to obtain the precision to disentangle the spectrum of observed hyperon states.

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## Summary and Conclusions (Cont'd)

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