Outline

➤ Physics Motivation
   * Hadronic structure
   * Strangeness physics
   * Reaction dynamics

➤ Formalism
   * Different observables

➤ Physics Models

➤ Selected Physics Results
   * Cross sections & spin observables
   * Photoproduction
   * Electroproduction

➤ Summary / Conclusions
N* Physics at CLAS

One of the main physics goals of the CLAS program is to probe the structure of the nucleon and its excited states.

The N* spectrum is the emblem of QCD just like the hydrogen atom spectrum is the emblem of quantum mechanics. (F. Lee)

Obtain accurate electromagnetic production cross sections and spin observables over a broad kinematic range.

Complete coverage of hadronic decay final state.

Determine the appropriate degrees of freedom to describe hadronic matter as a function of the relevant energy/distance scale.

Better understand the connections between the different scales.
Why Strangeness Production?

Most of what we know about the N* spectrum comes from:

\[ \pi + N \rightarrow (N^* \text{ or } \Delta^*) \rightarrow \pi + N \text{ or } \pi + \Delta \]

Processes involving strange particle production are complementary.

\[ \gamma^{(*)} + N \rightarrow (N^* \text{ or } \Delta^*) \rightarrow K + Y \]
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(different couplings involved)
“Missing” Quark Model Baryons

The constituent quark model predicts more states than seen experimentally.

Perhaps these “missing” states decay into KY channels.

– Focus on \( W > 1.6 \) GeV.  

– Supported by quark models and recent data.

"Missing" Quark Model Baryons


(SAPHIR, GRAAL, SPring–8, CLAS)

\[ \begin{array}{|c|c|} \hline \textbf{N* Resonances} & \textbf{Effective Degrees of Freedom} \\ \hline \textbf{****} & \textbf{CQM} \\ \text{or} & \textbf{CQM + flux tubes} \\ \textbf{***} & \textbf{Quark–diquark clustering} \\ \text{or} & \textbf{CQM} \\ \textbf{**} & \textbf{CQM + flux tubes} \\ \text{or} & \textbf{Quark–diquark clustering} \\ \textbf{*} & \textbf{CQM} \\ \hline \end{array} \]

\[ \begin{array}{cccc} S_{11}(1535), & S_{11}(1650), & S_{11}(2090), & S_{11}(2000), \\ P_{11}(1440), & P_{11}(1710), & P_{13}(1900), & F_{17}(1990), \\ D_{13}(1520), & D_{13}(1700), & D_{15}(2080), & F_{15}(2000), \\ & D_{15}(1675), & D_{15}(2200), & F_{15}(1680), \\ & & & F_{15}(1680), \\ & & & G_{17}(2190), \\ & & & G_{19}(2250), \\ & & & H_{19}(2220) \\ \end{array} \]
## The Current Landscape

### $N^* \rightarrow KY$

<table>
<thead>
<tr>
<th>State</th>
<th>PDG</th>
<th>B.R. $(K\Lambda)$</th>
<th>B.R. $(K\Sigma)$</th>
<th>$A_{1/2}$ (GeV$^{1/2}$)</th>
<th>$A_{3/2}$ (GeV$^{1/2}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$N^*(1650) S_{11}$</td>
<td>****</td>
<td>3-11%</td>
<td>-</td>
<td>0.053±0.016</td>
<td></td>
</tr>
<tr>
<td>$N^*(1675) D_{15}$</td>
<td>****</td>
<td>&lt;1%</td>
<td>-</td>
<td>0.019±0.008</td>
<td>0.015±0.009</td>
</tr>
<tr>
<td>$N^*(1680) F_{15}$</td>
<td>****</td>
<td>-</td>
<td>-</td>
<td>-0.015±0.006</td>
<td>0.133±0.012</td>
</tr>
<tr>
<td>$N^*(1700) D_{13}$</td>
<td>***</td>
<td>&lt;3%</td>
<td>-</td>
<td>-0.018±0.013</td>
<td>-0.002±0.024</td>
</tr>
<tr>
<td>$N^*(1710) P_{11}$</td>
<td>***</td>
<td>5-25%</td>
<td>-</td>
<td>0.009±0.022</td>
<td></td>
</tr>
<tr>
<td>$N^*(1720) P_{13}$</td>
<td>***</td>
<td>1-15%</td>
<td>-</td>
<td>0.018±0.03</td>
<td>-0.019±0.020</td>
</tr>
<tr>
<td>$N^*(1900) P_{13}$</td>
<td>**</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>$N^*(1990) F_{17}$</td>
<td>**</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>$N^*(2000) F_{15}$</td>
<td>**</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
</tbody>
</table>

### $\Delta^* \rightarrow K\Sigma$

<table>
<thead>
<tr>
<th>State</th>
<th>PDG</th>
<th>B.R. $(K\Sigma)$</th>
<th>$A_{1/2}$ (GeV$^{1/2}$)</th>
<th>$A_{3/2}$ (GeV$^{1/2}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Delta^*(1900) S_{31}$</td>
<td>**</td>
<td>-</td>
<td>?</td>
<td></td>
</tr>
<tr>
<td>$\Delta^*(1905) F_{35}$</td>
<td>****</td>
<td>-</td>
<td>0.026±0.011</td>
<td>-0.045±0.020</td>
</tr>
<tr>
<td>$\Delta^*(1910) P_{31}$</td>
<td>****</td>
<td>-</td>
<td>0.003±0.014</td>
<td></td>
</tr>
<tr>
<td>$\Delta^*(1920) P_{33}$</td>
<td>***</td>
<td>2.1%</td>
<td>?</td>
<td></td>
</tr>
<tr>
<td>$\Delta^*(1930) D_{35}$</td>
<td>***</td>
<td>-</td>
<td>-0.009±0.028</td>
<td>-0.018±0.028</td>
</tr>
<tr>
<td>$\Delta^*(1940) D_{33}$</td>
<td>*</td>
<td>-</td>
<td>?</td>
<td>?</td>
</tr>
<tr>
<td>$\Delta^*(1950) F_{37}$</td>
<td>****</td>
<td>-</td>
<td>-0.076±0.012</td>
<td>-0.097±0.010</td>
</tr>
</tbody>
</table>

**We have significant room for improvement!!**

Daniel S. Carman, Ohio University  
N*2005 Workshop -- October 12–15, 2005
Cross Sections

\[ \gamma + p \rightarrow K^+ + \Lambda \]

Ref. B. Saghai
nucl-th/0105001

\[ N^*(1895) \]

Bennhold I: Born terms
- t: \( K^*(892), K_1(1270) \)
- s: \( S_{11}(1650), P_{11}(1710), P_{13}(1720) \)

Bennhold II: Bennhold I + \( D_{13}(1895) \)

Saghai: Bennhold I + u: \( P_{01}(1810), P_{03}(1890) \)
- Proper treatment of off-shell effects (for \( s \geq 3/2 \))
Polarization Observables

Most of our understanding about the reaction mechanism comes from unpolarized experiments.

- This gives access only to limited information.

Polarization provides information about the contributing amplitudes.

Access underlying dynamics via both single and double polarization.

- $\tilde{\gamma}(\omega) + p \rightarrow K^+ + \tilde{Y}$  
  **Beam Asymmetry**

- $\gamma(\omega) + p \rightarrow K^+ + \tilde{Y}$  
  **Induced Polarization**

- $\tilde{\gamma}(\omega) + p \rightarrow K^+ + Y$  
  **Transferred Polarization**

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Hadrodynamic Models

- Isobar models based on effective Lagrangian.
  
  (Mart, Bennhold, Janssen)

- Features primarily due to s–channel resonances.
  - \( t \)-channel contains only \( K \) and \( K^* \).
  - Coupling strengths set by fits to existing data.
  - Parameters set by coupled–channels study.
  - Recent addition of \( u \)-channel \( Y^* \) resonances.

- Effective at low to moderate energies.

Regge Models

- Models based on \( t \)-channel Regge exchange.
  
  (Guidal, Laget, Vanderhaeghen)

- NO s–channel resonances included.

- Very few adjustable parameters.

- Effective at moderate to higher energies.
**CLAS Spectrometer**

**Characteristics:**

**Electron Coverage:** \( \theta : 15-50^\circ \)

**Hadron Coverage:**

\( \theta : 15-140^\circ, \phi : 80\% \ 2\pi \)

**Resolution:**

\( \Delta p/p \sim 1-2\% \)

\( \Delta \theta, \Delta \phi \sim 2 \text{ mrad} \)

\[
\mathcal{L} = 1 \times 10^{34} \text{ cm}^{-2}\text{sec}^{-1} \\
\mathcal{F}_\gamma = 1 \times 10^7 /\text{s}
\]

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Cross Section Extraction

Electroproduction example

\[ \frac{d^2\sigma_i}{d\Omega_K^*} = \frac{1}{\Gamma_v \Delta Q^2 \Delta W \Delta \cos \theta_K^* \Delta \phi} \frac{R_i N_i}{\eta_i} \frac{1}{N_0(N_A \rho t/M_t)} \]

**Signal & Background Fits**

**Acceptance Corrections**

**Radiative Corrections**

**Live Time & Efficiency Corrections**

**Systematic Studies (12%)**

**Momentum Corrections**

**Bin Centering Factors**
Cross Section Extraction

\[ \frac{d^2\sigma_i}{d\Omega^*_K} = \frac{1}{\Gamma_v \Delta Q^2 \Delta W \Delta \cos \theta^*_K \Delta \phi} \frac{R_i N_i}{\eta_i} \frac{1}{N_0(N_A \rho t/M_t)} \]

Signal & Background Fits
Acceptance Corrections
Radiative Corrections
Live Time & Efficiency Corrections

Systematic Studies (12%)
Momentum Corrections
Bin Centering Factors

Electroproduction example

Daniel S. Carman, Ohio University
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Hyperon decays weakly via:

\[ \Lambda \rightarrow p\pi^- \]

The polarization of the \( \Lambda \) is "betrayed" by angular distribution of the proton.

\[
\frac{dN^\pm_p}{d(\cos \theta_p^*)} = N^\pm [1 + \alpha P_\Lambda \cos \theta_p^*]
\]

\[ P_\Lambda = P^o \pm P_b P' \]

No polarimeter needed!
Energy Distributions

\[ \gamma + p \rightarrow K^+ + \Lambda \]

Sample of ~1400 CLAS points.

Forward angles | Backward angles
---|---
M=1950 MeV | M=1890 MeV
\( \Gamma = 100 \) MeV | \( \Gamma = 200 \) MeV

Guidal – 1999
Bennhold – 2002
Janssen – 2002

Existing models perform poorly

But, **NOT** yet fit to this CLAS data!!

Agreement in CLAS K and Kp final states.


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Energy Distributions

\[ \gamma + p \rightarrow K^+ + \Sigma^0 \]

Sample of ~1300 CLAS points.

One peak at 1.9 GeV with an angle-dependent shape.

Existing models perform poorly

But, NOT yet fit to this CLAS data!!

Agreement in CLAS K and Kp final states.

Guidal − 1999
Bennhold − 2002
Janssen − 2002


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Cross Section Analysis

Within the Regge exchange picture:

\[
\frac{d\sigma}{dt} = \mathcal{D}(t) \left( \frac{s}{s_0} \right)^{2\alpha(t) - 2} \Rightarrow \frac{d\sigma}{dt} \propto \frac{1}{s^2}
\]

\[\gamma + p \to K^+ + \Lambda\]

\[\gamma + p \to K^+ + \Sigma^0\]


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Induced Polarization

\[ \gamma + p \rightarrow K^+ + \bar{\Lambda} \]

\[ \gamma + p \rightarrow K^+ + \bar{\Sigma}^0 \]

- Full CLAS data set
- SAPHIR data set
- Deviations apparent with models over full kinematics.

- Transferred polarization \( C_x, C_z \) (see Bradford talk).

Guidal – 1999
Benhold – 2002
Janssen – 2002

McNabb (CLAS), PRC 69, 042201 (R) (2004)

Similar signatures to electroproduction
Higher-Level Analysis

Decays of Baryon Resonances into $\Lambda K^+$, $\Sigma^0 K^+$ and $\Sigma^+ K^0$

A.V. Sarantsev$^{1,2}$, V.A. Nikonov$^{1,2}$, A.V. Anisovich$^{1,2}$, E. Klempt$^3$, and U. Thoma$^{1,3}$

$^1$ Helmholtz–Institut für Strahlen– und Kernphysik, Universität Bonn, Germany
$^2$ Petersburg Nuclear Physics Institute, Gatchina, Russia
$^3$ Physikalisches Institut, Universität Gießen, Germany

June 7, 2005

Abstract. Cross sections, beam asymmetries, and recoil polarizations for the reactions $\gamma p \rightarrow \Lambda^+\Lambda$; $\gamma p \rightarrow K^+\Sigma^+$, and $\gamma p \rightarrow K^0\Sigma^+$ have been measured by the SAPHIR, CLAS, and LEPS collaborations with high statistics and good angular coverage for center-of-mass energies between 1.6 and 2.3 GeV. The combined analysis of these data with data from $\pi$ and $\eta$ photoproduction reveals evidence for new baryon resonances in this energy region. A new $P_{13}$ state with mass 1840 MeV and width 140 MeV was observed contributing to most of the fitted reactions. The data demand the presence of two $D_{13}$ states at 1870 and 2170 MeV.


<table>
<thead>
<tr>
<th>Observable</th>
<th>$N_{data}$</th>
<th>$\chi^2$</th>
<th>$\chi^2/N_{data}$</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\sigma(\gamma p \rightarrow \Lambda K^+)$</td>
<td>720</td>
<td>804</td>
<td>1.12</td>
<td>4</td>
</tr>
<tr>
<td>$\sigma(\gamma p \rightarrow \Lambda K^+)$</td>
<td>770</td>
<td>1282</td>
<td>1.67</td>
<td>2</td>
</tr>
<tr>
<td>$P(\gamma p \rightarrow \Lambda K^+)$</td>
<td>202</td>
<td>374</td>
<td>1.85</td>
<td>1</td>
</tr>
<tr>
<td>$\Sigma(\gamma p \rightarrow \Lambda K^+)$</td>
<td>45</td>
<td>62</td>
<td>1.42</td>
<td>15</td>
</tr>
<tr>
<td>$\sigma(\gamma p \rightarrow \Sigma^0 K^+)$</td>
<td>660</td>
<td>834</td>
<td>1.27</td>
<td>1</td>
</tr>
<tr>
<td>$\sigma(\gamma p \rightarrow \Sigma^0 K^+)$</td>
<td>782</td>
<td>2446</td>
<td>3.13</td>
<td>1</td>
</tr>
<tr>
<td>$P(\gamma p \rightarrow \Sigma^0 K^+)$</td>
<td>95</td>
<td>166</td>
<td>1.76</td>
<td>1</td>
</tr>
<tr>
<td>$\Sigma(\gamma p \rightarrow \Sigma^0 K^+)$</td>
<td>45</td>
<td>20</td>
<td>0.46</td>
<td>35</td>
</tr>
<tr>
<td>$\sigma(\gamma p \rightarrow \Sigma^+ K^0)$</td>
<td>48</td>
<td>104</td>
<td>2.20</td>
<td>2</td>
</tr>
<tr>
<td>$\sigma(\gamma p \rightarrow \Sigma^+ K^0)$</td>
<td>120</td>
<td>109</td>
<td>0.91</td>
<td>5</td>
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<tr>
<td>$\sigma(\gamma p \rightarrow \rho \pi^0)$</td>
<td>1106</td>
<td>1654</td>
<td>1.50</td>
<td>8</td>
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<tr>
<td>$\sigma(\gamma p \rightarrow \rho \pi^0)$</td>
<td>861</td>
<td>2354</td>
<td>2.74</td>
<td>3.5</td>
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<tr>
<td>$\Sigma(\gamma p \rightarrow \rho \pi^0)$</td>
<td>469</td>
<td>1606</td>
<td>3.43</td>
<td>2</td>
</tr>
<tr>
<td>$\Sigma(\gamma p \rightarrow \rho \pi^0)$</td>
<td>593</td>
<td>1702</td>
<td>2.87</td>
<td>2</td>
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<tr>
<td>$\sigma(\gamma p \rightarrow \pi^+ \eta)$</td>
<td>1583</td>
<td>4524</td>
<td>2.86</td>
<td>1</td>
</tr>
<tr>
<td>$\sigma(\gamma p \rightarrow \pi^+ \eta)$</td>
<td>667</td>
<td>608</td>
<td>0.91</td>
<td>35</td>
</tr>
<tr>
<td>$\sigma(\gamma p \rightarrow \eta \pi^0)$</td>
<td>100</td>
<td>158</td>
<td>1.60</td>
<td>7</td>
</tr>
<tr>
<td>$\Sigma(\gamma p \rightarrow \eta \pi^0)$</td>
<td>51</td>
<td>114</td>
<td>2.27</td>
<td>10</td>
</tr>
<tr>
<td>$\Sigma(\gamma p \rightarrow \eta \pi^0)$</td>
<td>100</td>
<td>174</td>
<td>1.75</td>
<td>10</td>
</tr>
</tbody>
</table>

Need to reduce ambiguities and improve fits with electroproduction data.
Structure Functions in Electoproduction

\[ \frac{d^4 \sigma}{dQ^2 dW d\Omega_K^*} = \Gamma_v \left[ \sigma_T + \epsilon \sigma_L + \epsilon \sigma_{TT} \cos 2\Phi + \sqrt{2\epsilon(\epsilon + 1)} \sigma_{LT} \cos \Phi \right] \]

\[ \sigma_i = f(Q^2, W, \cos \theta_K^*) \] only

- For each bin in \( W, Q^2, \cos \theta_K^* \) perform fit of the form:
  \[ \sigma = A + B \cos 2\Phi + C \cos \Phi \]

- Provide tomography of structure functions over full kinematic space of the nucleon resonance region.

\[ Q^2 : 0.5 \rightarrow 3.5 \text{ GeV}^2 \quad W : 1.6 \rightarrow 2.4 \text{ GeV} \]

Full coverage in \( K^+ \) solid angle.
Structure Functions in Electoproduction

\[
\frac{d^4\sigma}{dQ^2dWd\Omega_K^*} = \Gamma_v \left[ \sigma_T + \epsilon \sigma_L + \epsilon \sigma_{TT} \cos 2\Phi + \sqrt{2\epsilon(\epsilon + 1)} \sigma_{LT} \cos \Phi \right]
\]

\[
\sigma_i = f(Q^2, W, \cos \theta_K^*) \quad \text{only}
\]

- For each bin in $W, Q^2, \cos \theta_K^*$ perform fit of the form:
  \[
  \sigma = A + B \cos 2\Phi + C \cos \Phi
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\]

Full coverage in $K^+$ solid angle
Structure Functions in Electoproduction

\[
\frac{d^4\sigma}{dQ^2 dW d\Omega_K^*} = \Gamma_v \left[ \sigma_T + \epsilon \sigma_L + \epsilon \sigma_{TT} \cos 2\Phi + \sqrt{2\epsilon(\epsilon + 1)} \sigma_{LT} \cos \Phi \right]
\]

\[\sigma_i = f(Q^2, W, \cos \theta_K^*) \text{ only}\]

For each bin in \(W, Q^2, \cos \theta_K^*\) perform fit of the form:

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Full coverage in \(K^+\) solid angle.
Electroproduction Cross Sections

$ep \rightarrow e' K^+ \Lambda$

$Q^2 = 0.65 \text{ (GeV/c)}^2$

CLAS, to be submitted (2005).

Daniel S. Carman, Ohio University

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Electroproduction Cross Sections

$ep \rightarrow e' K^+ \Sigma^0$

$Q^2 = 0.65 \ (GeV/c)^2$

CLAS, to be submitted (2005).

Daniel S. Carman, Ohio University
L/T Separation I

L and T structure functions are typically extracted using the Rosenbluth approach.

With CLAS we can also perform a simultaneous fit that constrains L, T, LT, and TT structure functions.

\[ \sigma_i = f(Q^2, W, \cos \theta_K^*) \] only

Reduces systematics!

\[ W = 1.85 \text{ GeV}, \quad Q^2 = 1.0 \text{ GeV}^2 \]
L/T Separation I

- Mohring (Hall C)
- Markowitz (Hall A)

CLAS, to be submitted (2005).
Fifth Structure Function

\[ \bar{e} + p \rightarrow e' + K^+ + \Lambda \]

Measure polarized beam asymmetry to extract fifth structure function.

\[ A_{LT'} = \frac{1}{P_e} \frac{N^+ - N^-}{N^+ + N^-} = \frac{1}{\sigma_0} \sqrt{2 \epsilon L (1 - \epsilon)} \sigma_{LT'} \sin \Phi \]

Calculations from:

- Mart/Bennhold
- Janssen
- Guidal

\[ \cos \theta_{K'} = -0.833 \]

\[ \cos \theta_{K'} = -0.500 \]

\[ \cos \theta_{K'} = -0.167 \]

\[ \cos \theta_{K'} = 0.167 \]

\[ \cos \theta_{K'} = 0.500 \]

\[ \cos \theta_{K'} = 0.833 \]

\[ W (GeV) \]

Substantial differences in the reaction dynamics.

\[ 2.567 \text{ GeV} \quad Q^2 = 0.70 \text{ (GeV/c)}^2 \]

Nasseripour (CLAS), to be submitted (2005).
Transferred Polarization

$\vec{e} + p \rightarrow e' + K^+ + \Lambda$

$(x',y',z')$ system

- Williams – 1992
- Bennhold – 2002
- Janssen – 2002
- Guidal – 1999

<table>
<thead>
<tr>
<th>Resonance</th>
<th>WJC92</th>
<th>BM02</th>
<th>J02</th>
</tr>
</thead>
<tbody>
<tr>
<td>$N^*(1650)$</td>
<td>*</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>$N^*(1710)$</td>
<td>*</td>
<td></td>
<td>*</td>
</tr>
<tr>
<td>$N^*(1720)$</td>
<td></td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>$N^*(1895)$</td>
<td></td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>$K^*(892)$</td>
<td>*</td>
<td>*</td>
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</tr>
<tr>
<td>$K_1(1270)$</td>
<td>*</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>$\Lambda(1405)$</td>
<td></td>
<td>*</td>
<td></td>
</tr>
<tr>
<td>$\Lambda(1800)$</td>
<td></td>
<td></td>
<td>*</td>
</tr>
<tr>
<td>$\Lambda(1810)$</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2.567 GeV
Summed over $Q^2$, $\Phi$

Carman (CLAS), PRL 90, 131804 (2003)
L/T Separation II

P' data can be used to extract the ratio $\frac{\sigma_L}{\sigma_T}$.

A complementary approach!

Extrapolating to $\theta_K^* = 0$:

$$ R = \frac{\sigma_L}{\sigma_T} = \frac{1}{\epsilon} \left( \frac{c_0}{P_{z'}^L} - 1 \right) $$

![Graph showing the separation of L/T in Q^2 (GeV^2)](image)

Raue/Carman (CLAS)
Niculescu (Hall C)
Mohring (Hall C)
Bebek (Cambridge)

W=1.72, 1.84, 1.98 GeV

Daniel S. Carman, Ohio University

Raue/Carman, PRC 71, 065209 (2005)

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Summary/Conclusions

The Hall B strangeness physics program:

- Designed to measure cross sections and all combinations of beam, target, and recoil polarization states.
  
  *Precision data -- broad kinematic coverage*

- Sensitive to high-mass baryons (>1.6 GeV) with large K–Y couplings and large photocoupling amplitudes.

So far we have found:

- Suggestive evidence of resonant structures in the data.
  
  *Both photo- and electroproduction*

- Existing theoretical models do not describe the data well in our kinematics.

- Polarization data is quite versatile and useful to study.

- Work needed to incorporate these data into the models.
  
  *Opportunity for significant new constraints*
BACKUP Slides
\[ \frac{d\sigma}{d\Omega_{E'}d\Omega_K^* dE'} = \Gamma_v \frac{d\sigma_v}{d\Omega_K^*} \]  

\textit{(For unpolarized target)}

\[ \frac{d\sigma_v}{d\Omega_K^*} = \sigma_0 \left[ 1 + h A_{T L'} + \vec{S} \cdot \vec{P}^0 + h (\vec{S} \cdot \vec{P}^t) \right] \]

\textbf{Unpolarized Cross Section}

\[ \sigma_0 = \mathcal{K} (R_{T L}^{00} + \epsilon_L R_L^{00} + \epsilon R_{TT}^{00} \cos 2\Phi + \sqrt{2\epsilon_L(1+\epsilon)} R_{TT}^{00} \cos \Phi) \]

\[ A_{T L'} = \frac{\mathcal{K}}{\sigma_0} \sqrt{2\epsilon_L(1-\epsilon)} R_{T L'}^{00} \sin \Phi \]

\textbf{Polarized beam}

\[ \begin{pmatrix} P_{x'}^0 \\ P_{y'}^0 \\ P_{z'}^0 \end{pmatrix} = \frac{\mathcal{K}}{\sigma_0} \begin{pmatrix} \sqrt{2\epsilon_L(1+\epsilon)} R_{T L}^{00} \sin \Phi + \epsilon R_{TT}^{00} \sin 2\Phi \\ R_{T}^{y0} + \epsilon_L R_L^{y0} + \sqrt{2\epsilon_L(1+\epsilon)} R_{T L}^{y0} \cos \Phi + \epsilon R_{TT}^{y0} \cos 2\Phi \\ \sqrt{2\epsilon_L(1+\epsilon)} R_{T L}^{z0} \sin \Phi + \epsilon R_{TT}^{z0} \sin 2\Phi \end{pmatrix} \]

\textbf{Induced polarization}

\[ \begin{pmatrix} P_{x'}' \\ P_{y'}' \\ P_{z'}' \end{pmatrix} = \frac{\mathcal{K}}{\sigma_0} \begin{pmatrix} \sqrt{2\epsilon_L(1-\epsilon)} R_{T L}^{x0} \cos \Phi + \sqrt{1-\epsilon^2} R_{TT}^{x0} \\ \sqrt{2\epsilon_L(1-\epsilon)} R_{T L}^{y0} \sin \Phi \\ \sqrt{2\epsilon_L(1-\epsilon)} R_{T L}^{z0} \cos \Phi + \sqrt{1-\epsilon^2} R_{TT}^{z0} \end{pmatrix} \]

\textbf{Transferred polarization}
Normalization Check

$\gamma + p \rightarrow \pi^+ + n$

CLAS data normalized to pion production.
(photoproduction)

A sampling of the comparison.

R.A. Schumacher and J. McNabb
Transferred Polarization

\[ \tilde{e} + p \rightarrow e' + K^+ + \bar{\Lambda} \]

\((x', y', z')\) system

Janssen – 2002

No 1.9 GeV resonance

\begin{align*}
S11(1895) \\
P11(1895) \\
P13(1895) \\
D13(1895)
\end{align*}

Model fit to existing data:

\begin{align*}
SAPHIR (1998) \\
SPring–8 (2003) \\
Hall C (2003) \\
Harvard–Cornell \\
Orsay
\end{align*}

\([2.567\text{ GeV}]\]

\[\text{Summed over } Q^2, \Phi\]

DSC, PRL 90, 131804 (2003)

\[\tilde{e} \rightarrow e' + K^+ + \bar{\Lambda} \]

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Transferred Polarization

\( \bar{e} + p \rightarrow e' + K^+ + \bar{\Lambda} \)

\[(x',y',z')\) system 

\[(x,y,z)\) system 

\( W \) (GeV)

\( P'x' \)

\( P'z' \)

\( 2.567 \text{ GeV} \)

Summed over \( Q^2 \) d\( \Omega^x \)

\( DSC, \text{ PRL 90, 131804 (2003)} \)

\( B7 \)

\( A3 \)

\( B7 \)

\( D4 \)

\( CT \)

\( BC \)

\( CT \)

\( DI \)

\( AX \)

\( \Omega \)

\( K \)

\( \sum \)

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Transferred Polarization

$\vec{e} + p \rightarrow e' + K^+ + \bar{\Lambda}$

$(x,y,z)$ system

Williams – 1992
Bennhold – 2002
Janssen – 2002
Guidal – 1999

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<th>BM02</th>
<th>J02</th>
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2.567 GeV
Summed over $Q^2, \Phi$

DSC, PRL 90, 131804 (2003)
Electroproduction Cross Sections

$e p \rightarrow e' K^+ \Lambda$

$Q^2 = 0.65 \ (GeV/c)^2$

CLAS, to be submitted (2005).

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Electroproduction Cross Sections

\[ e p \rightarrow e' K^+ \Sigma^0 \]

\[ Q^2 = 0.65 \ (\text{GeV}/c)^2 \]

**CLAS, to be submitted (2005).**

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