Hyperon Physics at Hall B, Jefferson Lab

Lei Guo, Florida International University
For the CLAS Collaboration
Overview

• Why study hyperons at CLAS
  – KY contribution to the nucleon resonances
  – Hyperon Polarization
  – Unanswered questions in hadron physics
  – Cascade physics

• Existing CLAS results

• Upcoming CLAS results

• The Future
Hyperons in CLAS

CEBAF Large Acceptance Spectrometer

CLAS is well suited for hyperon physics: Large Acceptance
Good K/π separation

A small sample of CLAS hyperon data
**Λ Polarization: Photoproduction**

\[ R \equiv \sqrt{P^2 + C_x^2 + C_z^2} \]

\[ \bar{R} = 1.01 \pm 0.01 \]

- consistent with unity
- 100% polarization with circularly polarized beam

Totally unexpected by hadrondynamic models

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

\[ (\frac{P^2 + C_x^2 + C_z^2}{2})^{1/2} \]

\[ R \text{ vs } \cos(\theta^*_K) \]

\[ R \text{ vs } W \]

Large polarization transfer along virtual photon direction

D. S. Carman et al. (CLAS)
KΛ contribution to the N* resonances

Cross section results shows hint of $N^* \rightarrow K\Lambda$

This contribution is corroborated by the motion of the recoil polarization of Λ
Induced polarization of $\Lambda$ in
\[ \gamma p \rightarrow K^+/K^{*+} \Lambda \]

$K^{+/K^{*+}}\Lambda$ contribution to $N^*$ are comparable
$\Lambda$ recoil polarization shows 0-crossing in both channels

$-0.55 \leq \cos \theta_{c.m.}^{K^*} < -0.45$

$-0.33 \leq \cos \theta_{c.m.}^{K^*} < 0.0$

Mccracken et al., PRC 81, 025201(2009)
What is the nature of $\Lambda(1405)$: 3-quark state with well defined Isospin? Or is it dynamically generated (I=0 VS I=1 contributions): Interference causes difference line shapes for different decays!
What we have learned in the S=1 hyperons at CLAS

• CLAS has collected the largest data set of hyperons in photoproduction/electroproduction
• Hyperons are usually produced polarized, sometimes in very unexpected ways
• KY/K*Y contributes to the N* resonances
• In order to extract the Quantum Numbers of the N* resonances:
  We need Partial wave analysis, Coupled channel analysis
  And more observables: Beam/target asymmetry, polarization transfer (circular/linear polarized photons, polarized p/n targets, ….), all under way
• Plenty to do during the Shut-down
From $S=1$ to $S=2,3$ hyperons

The baryon decuplet $J=3/2$

The baryon octet $J=1/2$

$N(\Omega) = N(\Delta^*)$

$N(\Xi) = N(N^*) + N(\Delta^*)$
Some historical perspective:  
History of $\Omega^-$ (sss) Baryon

First measurement of $J(\Omega^-)$  
at SLAC:  $\Xi_c^0 \rightarrow \Omega^- K^+$, $\Omega^- \rightarrow \Lambda K^-$  

$J(\Omega^-)=3/2$, if $J(\Xi_c^0)=1/2$  

Barnes et al, PRL 12:204, 1964, $K^- p \rightarrow K^0 K^+ \Omega^-$  

Aubert et al, PRL.97:112001, 2006
**Ω⁻ (sss) Cross section and production mechanism**

A. Afanasev:

- Production mechanism for Ω⁻ in photoproduction unknown but extremely interesting:
  - None of the constituent quark(s) is from the target (ΔS=+3)
- Cascading decay from intermediate Y*?
- Various models predict σ~0.4-2nb at Eγ~7GeV

V. Shklyar (Effective Lagrangian)

- SLAC upper limit: 17nb@20GeV

Abe et al, PRD32, 2869 (1985)
The status of excited (PDG***) $\Omega/\Xi$ baryons (half a century later)

<table>
<thead>
<tr>
<th></th>
<th>$\Omega$</th>
<th>$\Xi$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$(J)^p$</td>
<td>$\Xi(2250)$</td>
<td>$\Xi(1530)$</td>
</tr>
<tr>
<td>$M$(MeV)</td>
<td>?</td>
<td>(3/2)$^+$</td>
</tr>
<tr>
<td>$\Gamma$(MeV)</td>
<td>2250</td>
<td>1530</td>
</tr>
</tbody>
</table>

- Very few $\Omega/\Xi$ baryons have been identified in the last 50 years.
- Even fewer have their quantum numbers determined.
- Kaon beam was the primary source for these states discoveries.
- Photon beam could be a powerful alternative.
Are $\Xi$ and $\Lambda$ polarized the same way?

• Diquark models:
  – Good diquark: isospin 0 and spin 0
  – $\Lambda((ud)s)$ polarization comes from $s$
  – $\Xi(u/d(ss))$, polarization comes from $u/d$?

• Purpose of studying $\Xi$ polarization
  – Probe production mechanism
  – Understand the origin of hyperon polarization
Recent CLAS6 results on $\Xi$

$E_\gamma$: 2.8-3.8 GeV


- Non-dedicated data, low beam energy, no vertex detector ...
- First high statistics exclusive $\gamma p$ experiment
- Future dedicated program at JLAB feasible and promising

- Data qualitatively consistent with t-channel hyperon production
- High spin hyperon resonances needed ($J>=3/2$)
What to expect at CLAS12 for $\Xi$ and $\Omega$

- Assuming $\sigma(\Omega^-) \sim 0.3\text{nb}$ (Afanasev, Roberts, Shklyar)
- $\sigma(\Xi^-) \sim 20\text{nb}$ (Oh, Nakayama)
  - SLAC inclusive: $117\text{nb}@20\text{GeV}$
- $\sigma(\Xi^-(1820/1690))$: around 1-5\text{nb}
- Luminosity: $10^{35}\text{cm}^{-2}\text{s}^{-1}$
- FT acceptance: $2.5 \sim 4.5^\circ (\theta)$
  - $0.5 \sim 4.5\text{GeV} (E_{e'})$
- $\Omega^-$ rate: 90/hr
- $\Xi^-$ rate: 3.6k/hr
- $\Xi^-(1690)/\Xi^-(1820): 0.2-0.9\text{k/hr}$

CLAS12 acceptance not folded in
\( \Xi^- \) induced polarization in photoproduction

- Data virtually background free (double kinematic constraints)
- \( g_{11} \) \( \Xi^- \) should not be polarized, If our naïve di-quark picture is correct,
- Statistics limited to study \( P(\cos\theta^*) \)

WE

NEED

CLAS12

(Higher beam energy, Higher cross section, Higher acceptance)
\( \Xi^- \) induced polarization in photoproduction

This data (2004, 2.8-3.8GeV): No beam/target polarization
Ongoing

The only direction \( \Xi \) can be polarized is out of plane (Parity conservation)
CLAS12 (with FT): polarization transfer for \( \Xi^- \)
\( P_\gamma(10-70\%) \), known on a event by event basis
CLAS6: Search for excited cascade resonances

$$\Xi^* \rightarrow \pi^- \Xi^0, \Lambda/\Sigma K^-$$

$$E_\gamma: 3.6-5.4 \text{GeV}$$

$$\overline{\Xi}^0/\Lambda/\Sigma$$ Decay chain not detected (can not determine JP)
Limited by beam energy, excited states other than $$\Xi(1530)$$ unlikely in CLAS6
We NEED CLAS12: Higher Energies, Xsections, acceptance …!
Spin-Parity determination of $\Xi^*$

- Spin can be measured by angular distributions (PWA)
- Parity measurement challenge: Minami ambiguity
  
  $\Xi^* \rightarrow Y (1/2^+) + M_1 (0^-)$: two solutions $J^{\pm P}$
- Double Moment Analysis (DMA)

$Y (1/2^+) \rightarrow B (1/2^+) + M_2 (0^-)$

Double moments: $H(lmLM) = \sum D^L_{Mm}(\theta_1, \phi_1) D^l_m(\theta_2, \phi_2)$

DMA:

$$H(11LM) = P(-1)^{J+\frac{1}{2}} \frac{2J+1}{\sqrt{2L(L+1)}} H(10LM)$$

Linear dependence gives simple, multiple tests for $J, P$

For any odd $L \leq 2J$ and $M \leq L$
Example: Parity measurement of $\Xi(1820)$

$\Xi(1820)$

CERN-SPS $\Xi$-Be reaction

Biagi et al., Z.Phys.C34, 175 (1987)

$\Xi(1820) \frac{3^-}{2}$ counts: $\sim 50$

Need to detect whole decay chain

CERN-SPS $\Xi$-Be reaction

Needs corroboration

CLAS12 estimate: $\sim 20k \Xi(1820)$

with complete decay chain

At CLAS12 (119 beam days)
CLAS12 Forward tagger (FT)

- $E_e$: 0.5-4.5 GeV
- $\Theta_e$: 2.5°-4.5°
- $E_\gamma$: 6.5-10.5 GeV
- $P_\gamma$: 10-70%

FT: not CLAS12 baseline equipment. Under construction (INFN et al.)

Vertex detector: 0.5 mm
Simulation and Background Estimation: $\Omega$

- Main source: Hadronic background
- Pythia Simulation: $\gamma p \rightarrow p + \text{anything}$
- S/B ratio 1:10

$\Lambda$ cut and vertex cut

- $\gamma p \rightarrow K^+K^+\bar{K}^0(\Omega^-)$
- Data almost background free if vertex cut is included
- Vertex resolution: 0.5mm
- Detached vertex cut: 2mm (5-10% loss of data)
## Expected W and X Rate at CLAS12

<table>
<thead>
<tr>
<th>Detected particles</th>
<th>Measured Decays</th>
<th>Overall Efficiency</th>
<th>Rate/hr</th>
<th>Total Detected</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Omega^-$</td>
<td>$K^+K^+K^0$</td>
<td>~4.6%</td>
<td>~4.2</td>
<td>~10k</td>
</tr>
<tr>
<td>$\Omega^-$</td>
<td>$K^+K^+K^0K^-$</td>
<td>$\Omega^-$</td>
<td>~0.6%</td>
<td>~1k</td>
</tr>
<tr>
<td>$\Xi^-$</td>
<td>$K^+K^+\pi^-$</td>
<td>$\Xi^-$</td>
<td>~10.0%</td>
<td>~600</td>
</tr>
<tr>
<td>$\Xi^-(1820)$</td>
<td>$K^+K^+K^-p$</td>
<td>$\Xi^- (1820)$</td>
<td>~1.0%</td>
<td>~7</td>
</tr>
</tbody>
</table>

Vertex Efficiency/Branching Ratio included

Preliminary
Summary

• Many results for $S=1$ hyperons have been published by CLAS
  – KY contribution to $N^*$ being determined
  – Polarization observables yield many interesting, and sometimes unexpected results
• CLAS12 could be a factory for the underexplored $\Omega/\Xi$ baryons
  – $\Omega^{-}$: Cross section can be measured
    production mechanism can be investigated
  – Excited cascade resonances:
    Spin-Parity can be determined
• $\Xi(1320)$ polarization: Insight to the production mechanisms
• $\Lambda/\Xi$ polarization measurement in target fragmentation region possible at CLAS12
• More exciting hyperon results to come from CLAS6/CLAS12