Cascade Spectroscopy at CLAS/CLAS12

Lei Guo, JLAB

for CLAS Collaboration

- **Overview**: Cascade physics is underexplored, and offers potential discovery
- Ground state $\Xi(1320)$: $\gamma p \rightarrow K^+ K^+ (\Xi^-)$
  - Few photon data existed. New CLAS g11 data: $\sim 70/pb^{-1}$, $E_0 = 4.0186$ GeV
  - **Cross section measurement**:
    - Production mechanism probe ($Y^* \rightarrow \Xi K?$)
- Search for excited $\Xi$ states
  - $\gamma p \rightarrow K^+ K^+ \pi^- (\Xi^0)$ analysis
  - **Future Spin-Parity measurement**
- Summary
Overview

- Cascade spectroscopy
  - Only 6 states with 3(4) stars
  - Most without spin-parity assignment
- Experimental verification of the $\Xi^*$ decoupling from $\Xi\pi$ predicted by Chao, Isgur, Karl
  - Main reason of narrow width of $\Xi$ resonances
- Can baryons in certain SU(6)$\otimes$O(3) multiplets be seen in the cascade spectrum, but missing in N$\pi$/NK$^-$ scattering data?
- Isospin-violating mass differences of $\Xi^*$: do they agree with quark model/lattice predictions?
  - Not feasible in N$^*$ sector
  - Photoproduction at JLAB offers unique alternative
CEBAF Large Acceptance Spectrometer@JLAB

Beam line and the target

Drift chambers

TOF counters

Cherenkov counters

6 Superconducting toroidal coils

Electromagnetic calorimeters

Bremsstrahlung tagged photon facility, photon energy resolution ~0.1% (New Tagger Energy Calibration)

CLAS Detector

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Search for $\Xi^{-*} \rightarrow \Xi^{0}\pi^{-}$

- Few excited cascade states observed
- CLAS ideal for $\Xi^{-*}$ in exclusive reaction:
  \[ \gamma p \rightarrow K^+ K^+ \pi^-(\Xi^0) \]
- Accessible $\Xi^*$ states:
- Complicated by background processes:
  - $\gamma p \rightarrow K^+ Y^*$, $Y^* \rightarrow Y^{**} \pi^-$, $Y^{**} \rightarrow K^+ \Xi^0$ 

<table>
<thead>
<tr>
<th>Excited cascades</th>
<th>Mass (GeV/c²)</th>
<th>Width (MeV/c²)</th>
<th>$\Xi\pi$ BR</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Xi^{-0}(1530)$</td>
<td>1.535</td>
<td>9.1</td>
<td>100%</td>
</tr>
<tr>
<td>$\Xi^{0}(1620)$</td>
<td>1.6-1.63</td>
<td>~22</td>
<td>$\Xi\pi$</td>
</tr>
<tr>
<td>$\Xi^{-0}(1690)$</td>
<td>1.69</td>
<td>&lt;30</td>
<td>seen</td>
</tr>
</tbody>
</table>

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First observation of $\Xi(1690) \rightarrow \Xi\pi$

Inclusive reaction: $\Sigma^{-}(C, Cu) \rightarrow (\Xi^{-}\pi^{+}) X$

No mention of $\Xi^{0}(1620)$; $\Xi^{0}(1690)$ claimed

Adamovich et al.
W89 Collaboration

After background subtraction
CLAS data: $\gamma p \rightarrow K^+ K^+ (X^-)$

With multiple Kaons in the final state, pion-veto is essential
- 1-sector RICH: 30% background suppression (2$K^+$)
- 2-sector: 56% background suppression


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Hyperon candidates decaying to $K\Xi$

$E_\gamma > 3.4 \text{GeV} \gamma p \rightarrow K^+ Y^*$

<table>
<thead>
<tr>
<th>$Y^*$</th>
<th>Mass (GeV)</th>
<th>Width (MeV)</th>
<th>BR$\rightarrow\Xi K$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Sigma(1940)$</td>
<td>1.94</td>
<td>200</td>
<td>N/A</td>
</tr>
<tr>
<td>$\Sigma(2030)$</td>
<td>2.03</td>
<td>180</td>
<td>&lt;2%</td>
</tr>
<tr>
<td>$\Lambda(2100)$</td>
<td>2.10</td>
<td>200</td>
<td>&lt;3%</td>
</tr>
</tbody>
</table>

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Hadronic model for cascade photoproduction:
Oh-Nakayama-Haberzettl model:

Radiative transition processes, various t,s channel processes

Only K and K* exchange included

Model includes low-lying N*/Δ/Y*

Y: $J^P = 1/2^-$ and $3/2^+$ hyperon resonances

$\Xi^{-}$ differential Cross sections compared with Oh-model: $d\sigma /d\cos(\theta_{\Xi})$

Data inconsistent with model without high-mass hyperons

Backward peaking reproduced by t-channel $Y^*$ production

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Interesting features of $M(\Xi K)$ spectra

- Statistics insufficient to be conclusive
- Not inconsistent with multiple $Y^* \rightarrow \Xi K$
- $d\sigma$ strength independent of $E_\gamma$ at low $M(\Xi K)$: Diffractive process?
- Early bubble chamber $K^-p$ data suggestive

D. Sharov, MSU, Master Thesis

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Polarization variables necessary to determine production mechanism

\[ \cos(\theta_{\Xi}) \]

Radiative processes

t-channel \ Y^*

\[ \Sigma_T \]

\[ \Sigma_B \]
Total cross section for $\gamma p \rightarrow K^+ K^+ \Xi^-$

Oh-model used earlier preliminary results (NSTAR05)

SLAC measurement: $117 \pm 17$ nb from inclusive reaction
(K. Abe et al., Phys. Rev. D32, 2869 (1985)}
$\Xi^-(1530)$ Cross section results

Total cross section:
$E_\gamma$: 3.35-3.85 GeV
\[ \sigma: 1.13 \pm 0.27 \text{nb} \]
$E_\gamma$: 3.85-4.75 GeV
\[ s: 1.77 \pm 0.40 \text{nb} \]

E$_\gamma$: 3.35-3.85 GeV

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$\gamma p \rightarrow K^+ K^+ \Xi^-, \Xi^- \rightarrow \pi^- \Xi^0$

$M(\Xi^-) - M(\Xi^0) = 5.5 \pm 1.8$ MeV

Clean sample of $\Xi$ events
\( \Xi^- (1320) \) polarization transfer

Phtoproducing polarized \( \Lambda \)  

Acceptance corrected decay angular distribution (Helicity frame)

- \( \Xi^- \) can be similarly produced polarized along production plane norm  
- Very sensitive to production mechanism

No polarization expected in helicity frame
Kinematic fitting results

Non-$\Xi^0$ events background consistent with out-of-target events background
$\Xi^0\pi^-$ invariant mass spectrum

$\Xi(1530)$ yields consistent with 100% $\Xi\pi$ BR (0.9±0.3)

Signal other than $\Xi(1530)$ insignificant

K* background

Non-$\Xi$ events background

CL>0.1

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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: $H(lmLM) = \sum L_{Mm}(\theta_1, \phi_1) L^l_{m_0}(\theta_2, \phi_2)$
  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 $M \leq L$
Parity measurement of $\Xi(1820)$

$\Xi(1820)$ counts: $\sim 50$

Fig. 4a, b. As in Fig. 3, but for the decay sequence $\Xi(1820) \rightarrow \Lambda \bar{K}^0$, $\Lambda \rightarrow p \pi^-$
Excited states

high energy data: $\gamma p \rightarrow K^+ K^+ \Xi^-, \Xi^- \rightarrow K^- \Lambda/\Sigma$

Detecting $\Lambda$ will enable the parity determination

$\Xi(1690)$

Possible degeneracy of $\Xi(1690)$

N. Mather, Quenched QCD (preliminary)
Prospects at CLAS12

- Photoproduction of cascades
  - $E_0 \sim 6.6$ GeV: $M(\Xi^{*-}) \sim 3$ GeV
  - $E_0 \sim 6.6$ GeV: $M(\Xi^{*-}) \sim 2.6$ GeV
  - $K/\pi/P$ separation up to 5 GeV

- Polarization measurement
  - Extracting production mechanism information
  - Hadronic picture/Quark-gluon framework

- Spin-parity measurement
  - Necessary to establish resonances
Summary and outlook

- CLAS good instrument for Cascade photoproduction
- $\Xi^{-}(1320)$ cross section obtained for $E_\gamma =2.8\sim4.7$ GeV ($\sigma(E_\gamma) \propto E_\gamma$ ?)
- Data suggestive of t channel production of $Y^* \to \Xi^- K^+$
- Polarization variables essential to understand production mechanism
- RICH detector will significantly improve data quality, and make $J^P$ measurements easier.
Reaction $\gamma p \rightarrow K^+ K^+ (\Xi^-)$

Misidentified pion background

$\gamma p \rightarrow K^+ \pi^+ (\Sigma^-)$,
$\pi^+$ misided as $K^+$

Linear band non-physica
Background events with $K^-$ detected

$$\gamma p \rightarrow K^+ K^+ K^- (\Lambda/\Sigma)^?$$

$$\gamma p \rightarrow K^- \Lambda(\Sigma) \phi$$

$$\gamma p \rightarrow K^+ K^+ (\Xi^*)$$
$\Xi^-$ differential Cross sections

$\frac{d\sigma}{d\cos(\theta_K)}$
$\Xi^-$ differential Cross sections: $d\sigma/dM(KK)$

Featureless spectra
$\Xi^-$ differential Cross sections $d\sigma / dM(K\Xi)$

Additional structure around 2.05 GeV at high $E_\gamma$
$\gamma p \rightarrow K^+ K^+ \Xi^-, \, \Xi^- \rightarrow \pi^- \Xi^0$

background events

One $\pi^+$ misidentified as $K^+$
$\gamma p \rightarrow K^+ \pi^+ \pi^- \, (\Lambda/\Sigma)$

Both $\pi^+$ misidentified as $K^+$
$\gamma p \rightarrow \pi^+ \pi^+ \pi^- \, (n)$

Real events: $\gamma p \rightarrow K^+ K^+ \Xi^-, \, \Xi^- \rightarrow \pi^- \Lambda$

MM($K^+K^+\pi^-$) (GeV/c$^2$)
Using out-of-vertex events for background estimate

Shaded events: Background from out of target events

Too wide, need Kinematic fitting

Background subtracted

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Simulation: $\gamma p \rightarrow K^+ K^+ \Xi^-, \Xi^- \rightarrow \pi^- \Xi^0$
Comparing $M(K^+ \pi^-)$: MC VS data

Up to 30% events could be $K^*$
Possible additional background:
\[ \gamma p \rightarrow K^+ K^* \Xi^0 \]

Simulation parameters:
- \( M(Y^*) = 1.9 \text{GeV} \)
- \( G(Y^*) = 120 \text{MeV} \)

Other bg processes not included

Peaking around 1.6GeV