Cascade Spectroscopy and Recent $\Xi^*$ Photo-production Results from CLAS

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Doubly Strange Baryons

\( \Xi^0 \) (\textit{uss}) \hspace{1cm} \Xi^- \) (\textit{dss})

- Only \textbf{six} “well established” cascade states.
- \textbf{11} reported \( \Xi \)'s counting 1 and 2 star states.
- \textbf{Three} have measurements for \( J^P \) and a guess for a \textbf{fourth}.

Difficulties with \( \Xi \)'s

- always part of a final state analysis which can be topologically complicated.
- production cross sections are \( \sim \) a few \( \mu \text{b} \).

<table>
<thead>
<tr>
<th>Particle</th>
<th>( I(J^P) )</th>
<th>Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \Xi(1318) )</td>
<td>( \frac{1}{2} \left( \frac{1}{2}^+ \right) )</td>
<td>****</td>
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<tr>
<td>( \Xi(1530) )</td>
<td>( \frac{1}{2} \left( \frac{3}{2}^+ \right) )</td>
<td>****</td>
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<tr>
<td>( \Xi(1620) )</td>
<td>( \frac{1}{2} \left( ?^- \right) )</td>
<td>*</td>
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<tr>
<td>( \Xi(1690) )</td>
<td>( \frac{1}{2} \left( ?^- \right) )</td>
<td>***</td>
</tr>
<tr>
<td>( \Xi(1820) )</td>
<td>( \frac{1}{2} \left( \frac{3}{2}^- \right) )</td>
<td>***</td>
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<tr>
<td>( \Xi(1950) )</td>
<td>( \frac{1}{2} \left( ?^- \right) )</td>
<td>***</td>
</tr>
<tr>
<td>( \Xi(2030) )</td>
<td>( \frac{1}{2} \left( \geq \frac{5}{2}^- \right) )</td>
<td>***</td>
</tr>
<tr>
<td>( \Xi(2120) )</td>
<td>( \frac{1}{2} \left( ?^- \right) )</td>
<td>*</td>
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<tr>
<td>( \Xi(2250) )</td>
<td>( \frac{1}{2} \left( ?^- \right) )</td>
<td>**</td>
</tr>
<tr>
<td>( \Xi(2370) )</td>
<td>( \frac{1}{2} \left( ?^- \right) )</td>
<td>**</td>
</tr>
<tr>
<td>( \Xi(2500) )</td>
<td>( \frac{1}{2} \left( ?^- \right) )</td>
<td>*</td>
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</tbody>
</table>

\textbf{Table}: \( \Xi^* \) summary table from Particle Data Group.
Xi* (1-4 stars) with N* and Δ* States (3,4 stars)

Figure: N*, Δ* and Ξ* states. N*'s are normalized to the proton mass and Ξ* are normalized to the ground state Ξ(1321).

- Ξ* are narrower than the N*.
- SU(3) symmetry requires a 1:1 correspondence between the N* and Δ*'s and the Ξ*.
- This means that many Ξ*'s are missing.
- Few Ξ* have know J^P, but the N* - Ξ* correspondence seems to hold for these.
**Xi* (1-4 stars) with N* and Δ* States (3,4 stars)**

Interesting aspects of Ξ’s

- Each Ξ* provides distinct measurement of up-down quark mass difference.
- Parity doublets.
- decay channels (eg. decay to η or ω).
- Exotics outside the standard model (eg. Ξ−−).

**Figure:** N*, Δ* and Ξ* states. N*’s are normalized to the proton mass and Ξ* are normalized to the ground state Ξ(1321). 
The $g12$ Experiment

Production Data – 70 calendar days, Spring 2008

$E_\gamma = 5.7 \text{ GeV}$

$I = 60, 65 \text{ nA}$

26.2 G triggers ($\sim 68 \text{ pb}^{-1}$)

Triggers:

- 2-prong, high-energy ($E_\gamma > 4.4 \text{ GeV}$)
- 3-prong, without electron tagger
- EC / CC lepton trigger (prescaled)

Photon beam incident on Hydrogen target

- unpolarized target.
- This is a continuation of a previous ($g6$) experiment with CLAS with a segmented start counter which allowed better than twice the DAQ rate.
The CLAS Detector

- six sectors — three ‘planes’
- radiator & electron tagger
- $\ell H_2$ or $\ell D_2$ target (others are possible)
- start counter (scintillator)
- toroidal magnets
- drift chambers (3x per sector)
- Čerenkov Detectors
- Time of Flight Detectors
- Electromagnetic Calorimeter
Cascade Event Profile

Basic Reaction: \( \gamma p \rightarrow K^+ K^+ \Xi^{*-} \)

- \( \Xi^{*-} \rightarrow \Xi^- (1320) \pi^0 \)
- \( \Xi^- \rightarrow \Lambda \pi^- \)
- \( \Lambda \rightarrow p \pi^- \)

Total topology:
\[ \gamma p \rightarrow p K^+ K^+ \pi^- \pi^- (\pi^0) \]

- Only events with a photon energy \( (E_\gamma) \) greater than 3 GeV were used in this analysis.
- 15% of total \( g12 \) statistics were used in this analysis.
Parameter Space for Cascade Analysis with CLAS

Basic Cuts Used

- \( E_\gamma > 3.0 \) GeV
- \( |\beta_{\text{TOF}} - \beta_{\text{momentum}}| < 0.02 \)
- \( |\Delta \text{Start} - \text{Time}(K^+K^+)| < 1 \) ns
- \( z - \text{vertex}(K^+K^+) = \text{inside target} \) (40 cm \( \ell \text{H}_2 \))

Other Parameters Involved with this Analysis

- TOF Energy Deposit
- Distance of Closest Approach (DOCA) of \( K^+K^+ \)
- using the decay \( \Xi^- \rightarrow \Lambda\pi^- \)
  - Invariant Mass \( (p\pi^-) \sim \Lambda(1116) \)
  - Missing Mass \( (K^+K^+\pi^-) \sim \Lambda(1116) \)
Figure: TOF energy deposit for all charged particles. Proton and pion lines are clear, kaon lines are obscured by statistics.
Figure: TOF energy deposit for all Kaons in $\gamma p \rightarrow K^+ K^+ X$ where the missing mass of the $K^+ K^+$ is the $\Xi(1320)$. 

[Graph showing TOF energy deposit vs. momentum]
TOF Energy Deposit - Kaon ID

Figure: TOF energy deposit for all Kaons in $\gamma p \rightarrow K^+ K^+ X$ where the missing mass of the $K^+ K^+$ is the $\Xi(1320)$. 
Figure: Missing mass of the $K^+ K^+$ for $\gamma p \rightarrow K^+ K^+ X$ with the TOF energy deposit cut (previous slide). 7% of statistics shown - further analysis is currently in progress.
Figure: Missing mass of the $K^+ K^+$ versus the DOCA of the $K^+ K^+$ in the reaction $\gamma p \rightarrow K^+ K^+ X$. Ground state $\Xi^-(1320)$ is clearly visible.
Figure: Missing mass of the $K^+K^+$ with DOCA$(K^+K^+)<1$ cm in the reaction $\gamma p \rightarrow K^+K^+X$. 15% statistics shown - total expected yield of $\Xi^-(1320)$: 2700.
\[ \Xi^- \rightarrow \Lambda\pi^-, \ \Lambda \rightarrow p\pi^- \]

Figure: Missing mass of the \((K^+ K^+)\) versus invariant mass of the \((p\pi^-)\) in the reaction \(\gamma p \rightarrow K^+ K^+ p\pi^- X\).
\( \Xi^- \rightarrow \Lambda \pi^-, \Lambda \rightarrow p \pi^- \)

Figure: Missing mass of the \((K^+ K^+)\) versus missing mass of the \((K^+ K^+ \pi^-)\) in the reaction \(\gamma p \rightarrow K^+ K^+ \Xi(1530)\). Analysis of this is currently ongoing.
\( \Xi^- \rightarrow \Lambda \pi^-, \Lambda \rightarrow p\pi^- \)

Figure: Missing mass of the \((K^+ K^+)\) with the invariant mass of \((p\pi^-)\) is the \(\Lambda(1116)\) in the reaction \(\gamma p \rightarrow K^+ K^+ p\pi^- X\). This includes the DOCA cut from the previous slides. 15\% statistics shown - total expected yield of \(\Xi^- (1320)\): 2700.
Future Analysis Plans

**g12 Cascade Analysis**
- Momentum corrections.
- Deeper study of Λ(1116) and TOF Energy Deposit.
- More statistics needed (15% of *g12* experiment was shown due to time and disk space requirements).

**Cascade Spectroscopy**
- There is a LOI in development for study of Ξ’s with 12 GeV upgrade and CLAS (if interested, please contact: Sasha Starostin at UCLA (starost@physics.ucla.edu))