KY Electroproduction at CLAS12

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Physics motivation: Study of the nucleon excitation spectrum to understand its ground state.

Search for Hybrid Baryons contributions in the low $Q^2$ evolution of the cross section for $K^+\Lambda$ electroproduction with CLAS12.

- Endorsement of a LoI by the Program Advisory Committee, PAC43.
- PAC44 Proposal Approved with A- rating – 100 days assigned

- CLAS12 and Forward Tagger (FT) @ JLAB: Experimental setup description.

- Simulation and Reconstruction of $K^+\Lambda$ electroproduction events in CLAS12

- Preliminary Results from Physics Runs: KY channel studied exploiting a subset of data from Fall 2018 Physics Runs in Hall B at Jefferson Lab.
Why N*?

Baryon Spectroscopy Reveals the Workings of QCD

“Nucleons are the stuff of which our world is made.

As such they must be at the center of any discussion of why the world we actually experience has the character it does.”

Nathan Isgur, NStar2000, Newport News, Virginia

Derek B. Leinweber – University of Adelaide
Why N*?

From the N* Spectrum to QCD

- Understanding the proton’s ground state requires understanding its excitation spectrum.
- The N* spectrum reflects the effective degrees of freedom and the forces.

From the Constituent Quark model to QCD.
Why N*?

From the N* Spectrum to QCD

Findings:

- Linear Regge trajectories
- Only lowest few in each band seen with 4★ or 3★ status
- $g(\pi N)$ couplings predicted to decrease rapidly with mass in each oscillator band
- Higher levels predicted to have larger couplings to $K\Lambda$, $K\Sigma$, $\pi\pi N$, ...

Hybrid baryons emerge as gluonic excitations of the nucleon to states where a constituent gluon combines with three quarks.

Hybrid Baryons in LQCD

QCD allows for the existence of Hybrid Baryons.


LQCD predicts several hybrid baryons states.

Differently from the case of hybrid mesons, hybrid baryons are predicted to have same quantum numbers of $N^*$ resonances.

The nucleon mass is shifted ~300 MeV to higher masses.

$m_\pi = 396$ MeV
Separating $Q^3G$ from $Q^3$ states: $A_{1/2, 3/2}(Q^2)$ and $S_{1/2}(Q^2)$

Transverse helicity amplitudes $A_{1/2}(Q^2)$, $A_{3/2}(Q^2)$ and longitudinal helicity amplitude $S_{1/2}(Q^2)$ allow to distinguish $Q^3G$ from $Q^3$ states.

Electroexcitation via quasi-real photon exchange can be considered for practical purposes photo-production.
Hybrid resonance contribution in the helicity representation

\[ \langle \lambda_f | T_r | \lambda_{\gamma \lambda p} \rangle = \sum_{N^*} \frac{M_r^2 - W^2 - i \Gamma_r (W) M_r}{\lambda_{\gamma} - \lambda_p} \]

where

- Resonance mass
- Energy dependent total width
- Invariant mass

The resonance electroexcitation amplitudes can be related to the $\gamma_N N^* \gamma$ electrocouplings $A_{1/2}, A_{3/2},$ and $S_{1/2}$ for nucleons

\[ \langle \lambda_R | T_{em} | \lambda_{\gamma \lambda p} \rangle = \frac{W}{M_r} \sqrt{\frac{8 M_N M_r q_{\gamma}}{4 \pi \alpha}} \sqrt{\frac{q_{\gamma}}{q_{\gamma}}} A_{1/2,3/2}(Q^2) \] with $|\lambda_{\gamma} - \lambda_p| = \frac{1}{2}, \frac{3}{2}$ for transverse photons,

\[ \langle \lambda_R | T_{em} | \lambda_{\gamma \lambda p} \rangle = \frac{W}{M_r} \sqrt{\frac{16 M_N M_r q_{\gamma}}{4 \pi \alpha}} \sqrt{\frac{q_{\gamma}}{q_{\gamma}}} S_{1/2}(Q^2) \] for longitudinal photons

The $N^*$ hadronic decay amplitudes can be expanded in partial waves of total momentum $J$

\[ \langle \lambda_f | T_{dec} | \lambda_R \rangle = \langle \lambda_f | T_{dec}^{J_r} | \lambda_R \rangle d_{\mu \nu}^{J_r} (\cos \theta^*) e^{i \mu \phi^*} \] where

\[ \langle \lambda_f | T_{dec}^{J_r} | \lambda_R \rangle = \frac{2 \sqrt{2} \pi \sqrt{2 J_r + 1} M_r \sqrt{\Gamma_{J_r}}}{\sqrt{\langle p_f^r \rangle}} \sqrt{\langle p_i \rangle} \]
Separating $Q^3G$ from $Q^3$ states

Transverse helicity amplitude $A_{1/2}(Q^2)$ and longitudinal helicity amplitude $S_{1/2}(Q^2)$ allow to distinguish $Q^3G$ from $Q^3$ states

A drop of the transverse helicity amplitudes $A_{1/2}(Q^2)$ faster than for ordinary three quark states, because of extra glue-component in valence structure

A suppressed longitudinal amplitude $S_{1/2}(Q^2)$ in comparison with transverse electro-excitation amplitude

I. G. Aznauryan et al., CLAS Collaboration, PHYSICAL REVIEW C 80, 055203 (2009)
Based on available knowledge, the signature for hybrid baryons may consist of:

- Extra resonances with $J^p=1/2^+$ and $J^p=3/2^+$, with masses from 1.8 GeV to 2.5 GeV and decays to $N\pi\pi$ or $KY$ final states.

- A drop of the transverse helicity amplitudes $A_{1/2}(Q^2)$ and $A_{3/2}(Q^2)$ faster than for ordinary three quark states, because of extra glue-component in valence structure.

- A suppressed longitudinal amplitude $S_{1/2}(Q^2)$ in comparison with transverse electro-excitation amplitude.
Scattered electrons are detected in Forward Tagger for angles from 2.5° to 4.5°. FT allows to probe the crucial $Q^2$ range where hybrid baryons may be identified due to their fast dropping $A_{1/2}(Q^2)$ amplitude and the suppression of the scalar $S_{1/2}(Q^2)$ amplitude.

$Q^2$ range of interest: 0.05 - 2 GeV$^2$

$$Q^2 = 4E_{Beam}E_e \sin^2 \frac{\theta}{2} \Rightarrow \theta < 5°$$

Scattered electrons are detected in the Forward Detector of CLAS12 for scattering angles greater than about 6°. Charged hadrons will be measured in the full range from 6° to 130°.
Experimental Setup: CEBAF

Important parameters:
- Injector energy: 45 MeV
- Temporal separation of the bunches 0.7 ns
- 1200 MeV each loop
- Halls A, B, C receive a 11 GeV electron beam, Hall D a 12 GeV electron with a 2 ns time interval
- High work frequency: almost continuum beam
- Maximal intensity of the beam: 200 μA
- $P_b$ (long. polarization) up to 90%

Components:
- Injector
- LINAC
- Refrigeration plant
- Magnets
- Experimental Halls
Experimental Setup: CLAS12

Projective geometry
Events produced in the forward direction
Experimental Setup: Forward Tagger (FT)

FT-Cal
- Measurement of the EM shower Energy
- Fast trigger signal

FT-Trck
- Measurement of the scattering angles $\theta$ and $\phi$

FT-Hodo
- Provides the $e/y$ separation
Simulation and FASTMC Reconstruction of $K^+\Lambda$ Electroproduction Events in CLAS12 using the Ghent RPR-2011 Model

How to determine the best run conditions for the experiment?

**Simulations**

Simulations have been performed using:

- **Event Generator** based on the Ghent RPR-2011 Model to produce electroproduction events and a
- **FASTMC** to simulate CLAS12 acceptance effects.
Available data on “Strange Calc” web site

StrangeCalc data have been used for the Event Generator.

[Image of StrangeCalc interface]

**StrangeCalc**

- **Reaction type**: Electroproduction
  - $p(e,e'K^+)\Lambda$
  - $p(e,e'K^+)\Sigma^0$
  - $n(e,e'\pi^-)p$
  - $p(e,e'K^0)\Sigma^+$

<table>
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<tr>
<th>Non-interference cross sections:</th>
<th>$d\sigma_U$</th>
<th>$d\sigma_L$</th>
<th>$d\sigma_T$</th>
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<tr>
<td>Interference cross sections:</td>
<td>$d\sigma_{TL}$</td>
<td>$d\sigma_{TR}$</td>
<td>$d\sigma_{TR'}$</td>
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<td>Induced recoil polarization:</td>
<td>$P^0_{yT}$</td>
<td>$P^0_{\parallel}$</td>
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<td>Transferred recoil polarization:</td>
<td>$P^1_{xT}$</td>
<td>$P^1_{yT}$</td>
<td>$P^1_{\parallel}$</td>
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<td>$E_{x,y,m}$</td>
<td>$E_{x,y,lab}$</td>
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<tr>
<td>Angular variable: $\cos \theta_{c.m.}$</td>
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<td>$-u$</td>
<td></td>
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<tr>
<td>Photon virtuality ($Q^2$):</td>
<td>Fixed</td>
<td>Range</td>
<td>List</td>
</tr>
</tbody>
</table>

Model:
- RPR-2011
- RPR-2007
- VR
  - No resonance contributions

Magnetic field: inbending or outbending?

Efficiency curve

**Efficiency**

\[
\text{Efficiency} = \frac{\text{Events passing the selection (fixed } Q^2)}{\text{Generated events (fixed } Q^2)}
\]

Single electron geometrical detection efficiency \( E = 11 \text{ GeV} \)

Outbending
TorCur= -3775 A

Inbending
TorCur= +3775 A
Strength of Torus current

$\Lambda$ ($\sigma=0.0216741$)

$\Sigma^0$ ($\sigma=0.0194596$)

$\Lambda$ & $\Sigma^0$

$\Lambda$ ($\sigma=0.011969$)

$\Sigma^0$ ($\sigma=0.0102411$)

$\Lambda$ & $\Sigma^0$

$K^+\Lambda$ and $K^+\Sigma^0$ overlap histograms

Advantage of high CLAS12 torus currents

6.6, GeV. -1500 A

6.6, GeV. -3375 A

e$'K^+$ missing mass to reconstruct $\Lambda$
e$'K^+$ missing mass to reconstruct $\Sigma^0$
Covering the whole $Q^2$ range

$Q^2$ vs $W$

Efficiency curve

Complementary ranges

$E = 6.6$ GeV
TorCur$= -3775$ A

$E = 8.8$ GeV
TorCur$= -3775$ A

$E = 11$ GeV
TorCur$= -3775$ A
12 GeV electron with CLAS12

Physics Run started in February 2018. RGK dedicated Run took data during Fall 2018.
Simulations have been performed using:

- **Event Generator** based on the Ghent RPR-2011 Model to produce electroproduction events
- **GEMC** to simulate CLAS12 acceptance effects.
- **CLARA Framework** to reconstruct events

- **1.6 GeV < W < 3 GeV**
- **$E_{\text{beam}} = 7.5$ GeV**
- **Torus/Solenoid current: 100%/ -100%**
- **529948 $K\Lambda$ Events analyzed**
5700 Run Conditions:

- $E_{\text{beam}} = 7.546$ GeV
- Total Events: $\sim 100 \text{ M}$
- Current: 30 nA
- Trigger Config: rgk v2.cnf1 e$^-\text{ in CLAS with PCAL+ECAL } \geq 300 \text{ MeV}$
  1 e$^-\text{ in FT and 1 charged fwd}$
- Torus/Solenoid current: 100%/ -100% (Negative Outbending, -3775)
- Target: LH$_2$
5700 e⁻K⁺: electron in FT

1.6 GeV < W < 3 GeV
Particle ID: electron in CLAS

Forward Detector

Central Detector

Positive particles

Negative particles

Courtesy of D. Carman
First Results: electron in CLAS

\[ p(e, e'K^+)X \]

\[ E_{\text{beam}} = 7.546 \text{ GeV} \]

1.6 GeV < W < 3 GeV

Courtesy of D. Carman
MESONEX-VERYSTRANGE Trains

- $e^-$ in FT + (F+F- or F+F+ or F+C+ or F-C+ or C+C+ or F+C- or C-C+ or F+C- or C+C-)
- **Runs:** 5681, 5682, 5683, 5684, 5700, 5701, 5702, 5703, 5704, 5705, 5706, 5707, 5708, 5771, 5772
- 7.5 GeV period (FT-on)
- **Torus/Solenoid Scale:** 1/-1
- **Torus/Solenoid Current:** -3770.0 A (negative outbending)/ 2416.0 A
- **Target:** LH$_2$

**Selection:**
- **Study of Exclusive channel:** final state with $e^- p \pi^- K^+$
- $|p_x(e^- p \pi^- K^+)| < 0.2$ GeV and $|p_y(e^- p \pi^- K^+)| < 0.2$ GeV
- ~ 186 M events analyzed
Trains Exclusive Channel: electron in FT

1.6 GeV < W < 3 GeV
Trains Exclusive Channel without $|p_{x,y}(e^- p \pi^- K^+)| < 0.2$ GeV selection: electron in FT

1.6 GeV < W < 3 GeV
Conclusions and Outlook

- Preliminary results for KY channel available using a subset of data
- Full implementation in CLAS12 simulation and reconstruction
  - GEMC
  - CLARA framework

Next step:

- Upgraded version for CLARA, new calibrated data will be available
- Reconstruction of the interaction strength from data
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Thank you
Bibliography

• *CLAS12 Forward Tagger (FT) Technical Design Report*, The CLAS12 Collaboration

• *Draft CLAS-Note, An Inner Calorimeter for CLAS/DVCS experiments*, I. Bedlinskiy, et Al.

• *CLAS/DVCS Inner Calorimeter Calibration*, R. Niyazov, S. Stepanyan

• *A Letter of Intent to the Jefferson Lab PAC43, Search for Hybrid Baryons with CLAS12 in Hall B*, A. D’Angelo et al.

• J. Dudek et al., 2012

• V. Mokeev et al., 2012, *Experimental study of the P11(1440) and D13(1520) resonances from the CLAS data on ep \rightarrow e\pi^+\pi^- p*

• I. G. Aznauryan et al., CLAS Collaboration, *PHYSICAL REVIEW C* 80, 055203 (2009)

