Recent Results From the GlueX Experiment

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Outline

• Physics motivation
• Photoproduction and GlueX overview
• GlueX light spectroscopy program
  o Focus: studying production mechanisms
  o Final states of interest
• Additional physics
  o $J/\psi$ threshold production
  o Baryon sector
Hadron Spectroscopy

• Many QCD states allowed beyond observed mesons and baryons
  ○ Theorized since 1960’s

  A SCHEMATIC MODEL OF BARYONS AND MESONS *

  M. GELL-MANN
  California Institute of Technology, Pasadena, California

  ... Baryons can now be constructed from quarks by using the combinations (q q q), (q q q q q), etc., while mesons are made out of (q q), (q q q q), etc. ...

  Phys. Lett. 8 (1964) 214

• Growing body of evidence for tetraquark, pentaquark candidates in recent years

LHCb collab., PRL 115, 072001 (2015)
Constructing Mesons

• States are classified by quantum numbers $J^{PC}$

• Using only $q\bar{q}$ constituents:
  
  - $J = L + S$
  - $P = (-1)^{L+1}$
  - $C = (-1)^{L+S}$

• $q\bar{q}$ allows for numbers:
  
  - $J^{PC} = 0^{-+}, 0^{++}, 1^{--}, 1^{+-}, 2^{++}, 2^{--}, ...$

• $q\bar{q}$ cannot form states:
  
  - $J^{PC} = 0^{--}, 0^{+-}, 1^{-+}, 2^{+-}, ..., ...$
  
  - Detection of such $J^{PC}$ implies non-$q\bar{q}$ structure!
Lattice Predictions in the Light Spectrum

Exotic states expected

Ideally, would like to establish spectrum of states
Candidates For Light Exotic States

• Potential search channels?
  ○ A state decaying to $\pi \eta^{(')}$ in a P-wave would be exotic

$$\pi^- p \rightarrow \pi^- \eta^{(')} p$$

“New data from GlueX and CLAS12 experiments at Jefferson Lab in this and higher mass region will be valuable...”

<table>
<thead>
<tr>
<th>Name</th>
<th>$J^{PC}$</th>
<th>Total Width MeV</th>
<th>Allowed Decay Modes</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\pi_1$</td>
<td>$1^{-+}$</td>
<td>81 – 168</td>
<td>$b_1 \pi, \pi \rho, \pi f_1, \pi \eta, \pi \eta', \eta a_1, \pi \eta(1295)$</td>
</tr>
<tr>
<td>$\eta_1$</td>
<td>$1^{-+}$</td>
<td>59 – 158</td>
<td>$\pi \eta_1, \pi \eta_2, \pi \eta(1300), \eta \eta', KK^A_1, KK^B_1$</td>
</tr>
<tr>
<td>$\eta'_1$</td>
<td>$1^{-+}$</td>
<td>95 – 216</td>
<td>$KK^B_1, KK^A_1, KK^*, \eta \eta'$</td>
</tr>
</tbody>
</table>
Probes To Study Light Mesons

- $e^+e^-$ (BESIII, Belle)
- Hadroproduction (COMPASS)
- Photoproduction (GlueX, LEPS)
  - Little data above $E_\gamma \approx 3$ GeV
  - To do:
    - Understand production mechanisms for well-established states at $E_\gamma \approx 8.5$ GeV
    - Study potential final states of interest
  - Future: amplitude analysis of individual/coupled channels
Features of Photoproduction

- Described by t-channel production at GlueX energies
  - Meson, pomeron exchange
  - Polarization: unique observable!
    - Provides additional information on exchanges (this talk’s focus)

⇒ Useful probe in search for exotic states!
GlueX Detector

• Large acceptance spectrometer for charged and neutral states
• Photon beam E:
  o 8-9 GeV polarized
  o Polarization $P_\gamma \approx 0.35$
  o 3 GeV masses reachable

More than 200 billion events:
  ▪ 2016: ~10 $pb^{-1}$
  ▪ 2017: ~45 $pb^{-1}$
  ▪ 2018: ~100 $pb^{-1}$
  ▪ Total hadronic cross section ~120 $\mu$b

Located at Jefferson Lab, Newport News, VA, USA
Production Asymmetry: $\gamma p \rightarrow \pi^0 p$

What is exchanged in photoproduction to produce a $\pi^0$?

Polarization allows us to distinguish positive and negative “naturality” contributions.
Experimental Measurement of Asymmetry $\Sigma$

Distribution of $\pi^0$ events has $\phi$-dependence:

$$\sigma(\phi) = \sigma_0(1 - P_\gamma \Sigma \cos(2(\phi - \phi_{\text{lin}})))$$

$$\Sigma = \frac{|\omega + \rho|^2 - |h + b|^2}{|\omega + \rho|^2 + |h + b|^2}$$

If $\Sigma = +1 \Rightarrow$ purely $\omega, \rho$

If $\Sigma = -1 \Rightarrow$ purely $h, b$
π⁰ and η Photoproduction Asymmetries

• Production mostly/all from natural exchange (e.g. ρ or ω)
  ○ No strong t dependence
• First measurement for η meson
• First publication with data after Jefferson Lab 12 GeV upgrade!
Asymmetry of $\pi^-$ Production

Charge exchange reaction:
- production changes with $t$
- restricts allowed isospin of exchanges
  (my thesis analysis)
Vector Meson Production

• Spin-1 kinematics are more complicated
• Additional decay angles \( \cos(\theta), \phi \)
  
  - Physics encoded in “spin-density matrix elements” \( \rho_{jk}^i \)

\[
W(\cos \theta, \phi, \Phi) = \frac{3}{4\pi} \left[ \frac{1}{2} (1 - \rho_{00}^0) + \frac{1}{2}(3\rho_{00}^0 - 1) \cos^2 \theta - \sqrt{2} \text{Re}\rho_{10}^0 \sin 2\theta \cos \phi + \rho_{1}^{0} \sin^2 \theta \cos 2\phi \right. \\
- \left. P_\gamma \cos 2\Phi (\rho_{11}^1 \sin^2 \theta + \rho_{00}^1 \cos^2 \theta - \sqrt{2} \text{Re}\rho_{10}^1 \sin 2\theta \cos \phi - \rho_{1}^{1} \sin^2 \theta \cos 2\phi) \\
- P_\gamma \sin 2\Phi (\sqrt{2} \text{Im}\rho_{10}^2 \sin 2\theta \sin \phi + \text{Im}\rho_{1}^{2} \sin^2 \theta \sin 2\phi) \right].
\]

Simplest model:
• Complete polarization transfer from photon
• Predicts \( \rho_{1}^{1} = -\text{Im} \rho_{1}^{2} = 0.5 \)
  
  (all other \( \rho_{jk}^i = 0 \))
Production Dynamics: $\gamma p \rightarrow \omega p$

Magenta: SLAC

Blue: GlueX

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full polarization transfer
More $\omega$ SDME’s

- 9 measurements. 8 independent.

**Magenta: SLAC**


**Blue: GlueX**

- full polarization transfer
Beyond Light Mesons: \( J/\psi \) Threshold Production

- Production also probes gluon distributions of proton and multiquark correlations
- See: L. Pentchev’s talk Friday 16:30 room 402 for more
- GlueX: happens to cover s-channel threshold of pentaquark candidate \( P_c(4450) \)!
**πη Final States**

\[ \gamma p \rightarrow \pi^- \eta \Delta^{++} \]

Reminder: a state decaying to πη in a P-wave is manifestly exotic!
Baryon Spectroscopy

- Baryon spectroscopy opportunities also available at GlueX
- Example: hyperon spectra

\[ \gamma p \rightarrow K^+ \Lambda^*, \Lambda^* \rightarrow K^- p \]

\[ \gamma p \rightarrow K^+ K^+ \Xi^-, \Xi^- \rightarrow \pi^- \Lambda \]
GlueX Summary

• Light spectroscopy program:
  o Orders of magnitude improvement in existing high energy photoproduction data
  o Pseudoscalar asymmetries and vector SDMEs: gaining insight into production mechanisms
  o Initial investigations of potential exotic channels underway

• Additional opportunities
  o $J/\psi$ threshold production
  o Baryon spectroscopy
  o ...and more!
Thank You!

Questions?
Spectroscopy: $\gamma p \rightarrow \pi^+ \pi^- p$

- Factor 1,000× more statistics than previous SLAC data
- Additional polarization observables at GlueX to exploit
Additional SLAC Data: Asymmetry of $\pi^-$ Production

- B.G Yu (Korea Aerospace U.), PRC 96, 025208 (16 GeV)
- J. Nys (JPAC), PLB 779, 77 (8.5 GeV)

- Charge exchange reactions: restricts allowed isospin of exchanges
  (my thesis analysis)

Black: GlueX data
Red: SLAC data (16 GeV)