Polarization Observable $E$ in the $\gamma(p,\pi^+)n$ Reaction

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Studying the Excited States of the Nucleon

- The location and properties of excited states reflect the dynamics and relevant degrees-of-freedom within the nucleons.

**Quark Models**

- Symmetric Constituent Quark Models predict overabundance of excited states ("missing" resonance problem)
- Quark-Diquark Models predict fewer states
- Quark and Flux-Tube Models predict increased number of states

\[ \gamma N \rightarrow N\pi, N\pi\pi, N\eta, YK, \ldots \]

Figure from: B. Krusche and S. Schadmand, Prog. Nucl. Phys. 51, 399 (2003)
Extraction of Resonance Parameters

- Measurements of eight observables needed to unambiguously determine the four amplitudes of single meson photoproduction:
  - differential cross section: $d\sigma/d\Omega$
  - single polarization observables: $P, T, \Sigma$
  - double polarization observables
- CLAS experiments with
  - polarized beam
  - polarized target (FROST, HD-Ice)
  - baryon recoil polarization (weak decay of hyperons)
The CEBAF Large Acceptance Spectrometer

- Large acceptance spectrometer
- Polarized tagged photon beam
- Polarized target (FROST, HD-Ice)

Pion Photoproduction: Observable $E$

- Circularly polarized beam / longitudinally polarized target

$$\left( \frac{d\sigma}{d\Omega} \right) = \left( \frac{d\sigma}{d\Omega} \right)_{\text{unpol}} \left( 1 - P_Z P_{\odot} E \right)$$

- Estimator for $E$

$$E = -\frac{1}{hP_z P_{\odot}} \frac{N^+ - N^-}{N^+ + N^-}$$

- Bound-nucleon background is accounted for by the dilution factor $h$.

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Polarized Beam and Target

- Circularly polarized photons
  - Tagged photon beam
  - $E_e = 1.65$ GeV, $2.48$ GeV
  - Electron beam polarization: $P_e \approx 85\%$

- Longitudinally polarized target
  - Frozen Spin Butanol ($C_4H_9OH$) with polarized free protons
  - $P_Z \approx 80\%$
  - Carbon target to study bound nucleon background

\[
P_\gamma = P_e \frac{4x - x^2}{4 - 4x + 3x^2}
\]
\( \gamma(p, \pi^+)X \) - Missing-Mass Distribution

- \( \pi^+ \) production off free and bound nucleons; Identification of reaction channel: \( m_X \approx m_N \)
- Background from reactions off bound (unpolarized) nucleons

**Dilution factor, \( h \):**
- Quenching of the asymmetry signal
- For the butanol target \((C_4H_9OH)\) the simple estimate is \( h \approx 10/74 \approx 0.14 \)
- \( h \approx 0.5 \) after event selections
$\gamma(p,\pi^+)n$ - Selected Preliminary Results

Summary

- CLAS Frozen-Spin-Target (FROST) Program
- Preliminary results for double-polarization observable $E$ in $\pi^+$ photoproduction
- About 600 data points covering a wide energy and angular range
  
  $-0.9 < \cos(\theta_{\pi,\text{cm}}) < +0.9$
  
  $1.24 \text{ GeV} < W < 2.30 \text{ GeV}$

  Average uncertainty for $E$: $\pm 0.07$ (statistical) and < 10% (systematics)

- The data will greatly constrain partial-wave analyses and reduce model-dependent uncertainties in the extraction of nucleon resonance properties, providing a new benchmark for comparisons with QCD-inspired models.

\[ \gamma p \rightarrow \pi^+ n \]