Overview of CLAS Physics

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Outline

1. Introduction
   - Physics with the CLAS Detector
   - The CLAS Detector at Jefferson Lab

2. The CLAS Excited Baryon Program
   - Double-Pion Production
   - Transition Form Factors

3. The CLAS Polarization Program
   - Hyperon Photoproduction

4. Summary and Outlook
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4. Summary and Outlook
Wide range of experiments covering mostly

- **Meson spectroscopy**
  
  → P. Eugenio, Tuesday: 10h20

- **N* Program (baryon spectroscopy, transition form factors)**
  
  → M. Williams, K. Park, V.C., this session

- **Nucleon structure (through)**
  
  - Elastic scattering
  - Deep inelastic scattering
    
    → S. Niccolai (GPD’s), Monday: 14h00

- **Nuclear transparency and nucleon correlations in nuclei**
What are the relevant degrees of freedom?

What are the corresponding effective interactions responsible for hadronic phenomena?

Models

Quarks and Gluons as Quasiparticles

ChPT

Nucleon and Mesons

pQCD

$q, g, q\bar{q}$
Search for *missing* resonances

Quark models predict many more baryons than have been observed

<table>
<thead>
<tr>
<th>N Spectrum</th>
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<table>
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<th>Δ Spectrum</th>
<th>***</th>
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<tbody>
<tr>
<td>7</td>
<td>3</td>
<td>6</td>
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⇒ according to PDG

⇒ little known
(many open questions left)

Possible solutions:

1. Quark-diquark structure

   one of the internal degrees of freedom is frozen

2. Have not been observed, yet

   Nearly all existing data result from \( \pi N \) scattering experiments

   ⇒ If the missing resonances did not couple to \( N\pi \), they would not have been discovered!!
Introduction
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Physics with the CLAS Detector
The CLAS Detector at Jefferson Lab

Overview of CLAS Physics

**CLAS Spectrometer**

- **Torus**
- **Tagger**
- **Drift Chambers**
- **TOF**
- **Cerenkov**
- **Calorimeters**

**Characteristics:**

- **Electron Coverage:** $\theta : 15–50^\circ$
- **Hadron Coverage:** $\theta : 15–140^\circ$, $\phi : 80\%$ 2$\pi$
- **Resolution:** $\Delta p/p \sim 1–2\%$
  $\Delta \theta, \Delta \phi \sim 2 \text{ mrad}$

$\mathcal{L} = 1 \times 10^{34} \text{ cm}^{-2} \text{sec}^{-1}$

$\mathcal{F}_\gamma = 1 \times 10^7 /\text{s}$
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The excited baryon program has two main components:

- **Establish the systematics of the spectrum**
  - Provides information on the nature of effective degrees of freedom in strong QCD

- **Probe resonance transitions at different distance scales**
  (electron beams are ideal to measure transition form factors)
  - Provides information on the confining forces of the 3-quark system
Resonances in $\gamma(\ast)p \rightarrow p\pi^+\pi^-$

- $2\pi$ channel sensitive to N*’s heavier than 1.4 GeV
- Provides complementary information to the $1\pi$ channel
- Many higher lying N*’s decay preferably to $N\pi\pi$ final states via intermediate states

Solid curves are from fits using the recent JM06 model with and without a new $\rho(1720)P_{33}$ state

- $3/2^+(1720)$
- $P_{33}(1720)$
Resonances in $\gamma(\ast)p \rightarrow p\pi^+\pi^-$

- **Background**
- **Resonances**

Combined analysis of preliminary real (M. Bellis) and also published virtual photon data (M. Ripani):

Fit needs both the candidate $\rho(1720)P_{33}$ and the $N(1720)P_{13}$ state.

Authors claim that combined fit of various single differential cross sections allowed to establish all significant mechanisms.
The CLAS-Collaboration phenomenological models (UIM/DR/JM) reproduce reasonably well comprehensive CLAS/world data on all observables in $N\pi/N\pi\pi$ electroproduction:

- **Isobars used in $N\pi\pi$ electroproduction**
  1. All well-established $N^* \to \pi^- \Delta^{++}$ decays + $3/2^+(1720)$
  2. All well-established $N^* \to \rho\pi$ decays + $3/2^+(1720)$
  3. Observed for the first time in CLAS data: $\pi^+D_{13}^0(1520)$, $\pi^+F_{15}^0(1685)$, and $\pi^-P_{33}^{++}(1640)$

- **Models can be used to evaluate $N^*$ electrocouplings**
  ➔ Information on contributing mechanisms will be used by EBAC for $N^*$ studies in advanced coupled channel analysis (Julia-Diaz, Lee, Phys. Rev. C76, 065201 (2007))
Roper Electro-Coupling Amplitudes $A_{1/2}, S_{1/2}$

Is Roper a 3-quark state?

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Is Roper a 3-quark state? Hybrid (glue) nature ruled out.
Roper Electro-Coupling Amplitudes $A_{1/2}$

- Bare electrocouplings (from I. Aznauryan)
- Dressed electrocouplings (accounting for only $N\pi$ in dressing)


Much better data (description) at $Q^2 < 0.6$ GeV$^2$ offer evidence for sizable contribution from meson-baryon cloud.
S_{11}(1535) Electro-Coupling Amplitudes A_{1/2}, S_{1/2}
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\begin{align*}
\bar{\gamma}p &\rightarrow K^+ + \bar{\Lambda} \\
\text{Circularly-polarized beam} \\
C_x/C_z \text{ characterize polarization transfer from beam to recoiling hyperon}
\end{align*}

(\(C_x\) and) \(C_z\) in Hyperon Photoproduction

Circularly-polarized beam

Possible relation: \(C_z \approx C_x + 1\)

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\( C_x \) and \( C_z \) in Hyperon Photoproduction

\[ R^2 \equiv P^2 + C_x^2 + C_z^2 \leq 1 \]

Conclusion:
\( \Lambda \) hyperons appear 100 \% spin polarized.

Kinematically not required, unknown origin!

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The Double-Polarization Program (FROST) at JLab:

- E 02-112 ⇒ Photoproduction of Hyperons ($K^+\Lambda (\Sigma^0)$, $K^0\Sigma^+$)
- E 03-105 ⇒ $\pi^0 p$, $\pi^+ n$ Photoproduction
- E 04-102
- E 05-012 ⇒ $\eta$ Photoproduction
- E 06-013 ⇒ $\pi^+\pi^-$ Photoproduction

The Polarized Deuterium-Target Program (HD-Ice target from BNL):

- E 06-101 ⇒ $\gamma n \rightarrow \pi^- p$, $\pi^+\pi^- n$, $K Y (K^0\Lambda$, $K^0\Sigma^0$, $K^+\Sigma^-$)

Polarized photon beams on unpolarized targets:

- g1, g8 ⇒ Reactions on Hydrogen ($\checkmark$)
- g13 ⇒ Reactions on Deuterium ($\checkmark$)
Many channels being analyzed:
- High statistics > 10 billion events
- High photon polarization from 1.3 – 2.1 GeV

Preliminary analysis of $\gamma p \rightarrow N\pi$
- $P_\gamma$ estimated at 0.8
- SAID prediction
- Data with statistical errors (no systematic)

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Hyperon Photoproduction

**Summary**
- Polarized photons
  - 1.1 - 2.3 GeV (linear)
  - 0.4 - 2.5 GeV (circular)
- Deuterium target
- 5·10^{10} events

**Status**
- Data collected Nov 2006 – Jun 2007
- Calibration soon complete
- At least 7 PhD theses in progress

**N* Physics**: γn → N* → ...
- K^0 Λ, K^0 Σ^0, K^+ Σ^−, K^{0*} Λ, K^+ Σ(1385)
- π^− p, π^− π^0 p, ω p

**Nuclear effects, YN interactions, pQCD**: γd → ...
- π^− p p, K^+ Λ p, K^0 Λ p, K^0 Σ^0 p, Φ n
- π^0 d, η d, ω d, ρ d, η' p n, p n

**Raw Beam Asymmetry**

**Raw asymmetry (assumed beam P = 1.0) vs. cos theta in CMS, Energy range 1.85 - 1.90 GeV**

**Very Preliminary!**
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Successful Excited-Baryon (Meson) Program using CLAS

- Improved statistics for previous measurements
- $P_{11}(1440)$, $D_{13}(1520)$, $S_{11}(1535)$ electrocouplings determined from CLAS data for the first time at $0.2 < Q^2 < 4.5$ GeV$^2$
- New data has revealed some hints for new N$^*$ resonances

Double-Polarization Program

- Complete determination of $K\Lambda$ amplitude
- Almost complete sets for $N\pi$, $N\eta$, $N\pi\pi$, ...

FROST completed with longitudinal target polarization

$\Rightarrow$ Program on transversely-polarized target in 2009

HD program scheduled to run in 2010