Report on NSTAR 2005 Workshop

V. Credé

¹Florida State University
Tallahassee, FL

Cascade Workshop at JLab, 12/03/2005
Outline

1. Introduction

2. N^*/Δ^* Spectroscopy
   - What are the problems?
   - The NSTAR 2005 Workshop

3. Experimental Status
   - Recent Results (reported at workshop)
   - New Experimental Approaches

4. Summary and Outlook
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4. Summary and Outlook
Search for *missing* resonances

Quark models predict many more baryons than have been observed

<table>
<thead>
<tr>
<th>N spectrum</th>
<th>****</th>
<th>***</th>
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<th>*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>11</td>
<td>3</td>
<td>6</td>
<td>2</td>
</tr>
<tr>
<td>Δ spectrum</td>
<td>7</td>
<td>3</td>
<td>6</td>
<td>6</td>
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</tbody>
</table>

⇒ according to PDG
⇒ little known
(many open questions left)

Possible solutions:

a) Quark-Diquark Structure

b) They have not been observed, yet

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

⇒ If the missing states did not couple to \( N\pi \),
they would not have been discovered!!
Parity Doublets

Nucleons

<table>
<thead>
<tr>
<th>J π</th>
<th>1/2+</th>
<th>1/2-</th>
<th>3/2+</th>
<th>3/2-</th>
<th>5/2+</th>
<th>5/2-</th>
<th>7/2+</th>
<th>7/2-</th>
<th>9/2+</th>
<th>9/2-</th>
<th>11/2+</th>
<th>11/2-</th>
<th>13/2+</th>
<th>13/2-</th>
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<td>Mass [MeV]</td>
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<td>1500</td>
<td>2000</td>
<td>2500</td>
<td>3000</td>
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<tr>
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<td>1700</td>
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<td>1895</td>
<td>1986</td>
<td>1990</td>
<td>2080</td>
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<td>2190</td>
<td>2200</td>
<td>2220</td>
<td>2250</td>
<td>2280</td>
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Introduction

N* / Δ* Spectroscopy

Experimental Status

Summary and Outlook

What are the problems?
The NSTAR 2005 Workshop

Parity Doublets

Nucleons

Mass [MeV]

1000 1500 2000 2500 3000

1 2 3 4 5

J π 1/2+ 1/2- 3/2+ 3/2- 5/2+ 5/2- 7/2+ 7/2- 9/2+ 9/2- 11/2+ 11/2- 13/2+ 13/2-

Is this compelling empirical data?

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Parity Doublets

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<td>1900</td>
<td>1520</td>
<td>1990</td>
<td>2190</td>
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Is this compelling empirical data?

- **Glozman:** "... and thus we have a complete and total, 100% ironclad proof that ..." (according to T. Cohen)
Parity Doublets

Is this compelling empirical data?

- Glozman: "... and thus we have a complete and total, 100% ironclad proof that ..." (according to T. Cohen)
- Cohen: "... and thus we have a faint hint of a whisper of the suggestion of the possibility that perhaps ..."
Let’s look for them ...

Atomic Spectra

- Discrete spectrum of absorption and emission lines
- Excitation spectrum of nucleon offers access to QCD
However, ... 

$N^*$ spectral lines look more like 

$\Rightarrow$ Baryons are broad and overlapping 

- Rescattering  
  $\Rightarrow$ Coupled-channel effects 
- Polarization (need complete experiment)
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Tallahassee, Florida
Program of the Workshop

- Focus session on coupled-channel analysis

- Recent experimental results, including Pentaquarks, and strangeness production

- Cascades

- Focus session on polarization

- Focus session on developments in theoretical description of baryon spectrum, including lattice QCD and coupled-channel unitarised chiral models
Coupled-Channel Analyses

Important in 2nd and 3rd resonance region

↓

Amplitude analysis of data

↓

Extract N* parameters

↓

Interpretations in terms of QCD
Coupled-Channel Analyses

- Unitary Isobar Models
  - MAID
  - JLab/Yerevan UIM
- Multi-Channel K-Matrix Models
  - SAID
  - Giessen Model, KVI Model
  - Kent State University (KSU)
- Carnegie-Mellon-Berkeley (CMB) Model
  - Recent applications: Zagreb, PITT-ANL, FSU-PITT
- Dynamical Reaction Models
  - Jülich, SL, DMT, Ohio-Utrecht, ...

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- **Dynamical Reaction Models**
  - Jülich, SL, DMT, Ohio-Utrecht, ...
Baryon Spectroscopy at BES: $J/\psi \to p\pi^- \bar{n} (\bar{p}\pi^+ n)$

Possible new state

- $M = 2065 \pm 3^{+15}_{-30}$ MeV/c$^2$
- $\Gamma = 175 \pm 12 \pm 40$ MeV/c$^2$

$\Rightarrow$ Prel. PWA favors $\frac{3}{2}^+$ (hep-ex/0405030)
Models developed from fits to Bonn data (SAPHIR)
⇒ Only reproduce the threshold region
Induced Polarization of the $\Lambda$ and $\Sigma^0$ Hyperon

CLAS results consistent with some older data from Bonn
Strangeness Production

⇒ Neither hadrodynamic nor Regge calculations reproduce the magnitudes or the trends seen in the hyperon polarization data

Data included in recent coupled-channel analysis (Sarantsev et al.):

- SAPHIR and CLAS
- Beam asymmetry data from SPring-8/LEPS for $K^+\Lambda$
- Recent $\pi^0/\eta$ data from CB-ELSA

⇒ New $P_{11}$ at 1840 MeV
⇒ Two $D_{13}$: at 1870 MeV and 2130 MeV
⇒ $\Delta(1940)D_{33}$ only $\Delta^*$ contributing to $K^+\Sigma^0$
Recent Results from the CB-ELSA Experiment

V. Credé
Report on NSTAR 2005 Workshop
V. Credé, O. Bartholomy, and The CB-ELSA Collaboration


**Graphical Representation**

The graph shows the differential cross section \( \frac{d\sigma}{d\Omega} \) in units of \( \mu b/sr \) as a function of \( \cos \theta_{cm} \) for different energy intervals:

- 1650 - 1700
- 1700 - 1750
- 1750 - 1800
- 1800 - 1850
- 1850 - 1900
- 1900 - 1950
- 1950 - 2000
- 2000 - 2050
- 2050 - 2100
- 2100 - 2150
- 2150 - 2200
- 2200 - 2250
- 2250 - 2300
- 2300 - 2400
- 2400 - 2500
- 2500 - 2600
- 2600 - 2800
- 2800 - 3000

The graph includes data from CB-ELSA, GRAAL, CLAS, and TAPS collaborations, with fits for the CB-ELSA data.
The angular coverage of new data allows determination of the total cross section.

CB-ELSA Isobar-Model Fit: (Data included)
- $\gamma p \rightarrow p\eta, \gamma p \rightarrow p\pi^0$ (CB-ELSA)
- $\gamma p \rightarrow p\eta$ (TAPS, low energies)
- $\Sigma (\bar{\gamma}p \rightarrow p\eta), \Sigma (\bar{\gamma}p \rightarrow p\pi^0)$ (GRAAL)
- $\Sigma (\bar{\gamma}p \rightarrow p\pi^0), \sigma (\gamma p \rightarrow n\pi^+)$ (SAID)

- Needs confirmation!
- No need for third S_{11}
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Summary and Outlook
Polarization: Single-Meson Production

\[
\frac{d\sigma}{d\Omega} = \sigma_0 \left\{ 1 - \delta_I \sum \cos 2\phi \\
+ \Lambda_x \left( -\delta_I H \sin 2\phi + \delta_\odot F \right) \\
- \Lambda_y \left( -T + \delta_I P \cos 2\phi \right) \\
- \Lambda_z \left( -\delta_I G \sin 2\phi + \delta_\odot E \right) \right\}
\]

\[\Leftrightarrow \text{Single-Meson Final States (7 Observables)}\]

- \(\delta_I, \delta_\odot\): Beam Polarization
- \(\Lambda_x, \Lambda_y, \Lambda_z\): Target Polarization
Polarization: 2-Meson Production \((\pi^+\pi^-, \pi^0\pi^0, \pi^0\eta, \ldots)\)

\[\gamma N \rightarrow N\pi\pi = \gamma N \rightarrow \Delta\pi \rightarrow N\pi\pi + \gamma N \rightarrow N\rho \rightarrow N\pi\pi, \text{ etc.}\]

- Many possibilities to be included
- Polarization treated in terms of density matrix for each quasi two-body (QTB) state
- C’est pas très efficace! (W. Roberts)

In addition:
- QTB treatment neglects contributions that are not QTB
- Interferences may be (largely) ignored
- Treating process as \(N\rho\), for example, will lead to results \((of\ some\ kind)\) \(\Rightarrow\) Interpretation may not be convincing
Polarization: 2-Meson Production \((\pi^+\pi^-, \pi^0\pi^0, \pi^0\eta, \ldots)\)

\[ \gamma N \rightarrow N\pi\pi = \]
\[ \gamma N \rightarrow \Delta\pi \rightarrow N\pi\pi + \]
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- Many possibilities to be included
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\[ I = I_0 \left\{ (1 + \vec{\Lambda}_i \cdot \vec{P}) + \delta_{\odot} \left( I^{\odot} + \vec{\Lambda}_i \cdot \vec{P}^{\odot} \right) + \delta_{\perp} \left[ \sin 2\beta \left( I^s + \vec{\Lambda}_i \cdot \vec{P}^s \right) \right] \cos 2\beta \left( I^c + \vec{\Lambda}_i \cdot \vec{P}^c \right) \right\} \]

\[ \Leftarrow \text{Double-Meson Final States} \]
\[ (15 \text{ Observables}) \]
Measurement of $I^\circ$ at CLAS

- Only one observable in $\pi\pi$, $I^\circ$, measured and published (S. Strauch et. al., PRL 95, 162003 (2005))
  ⇒ Circularly-polarized beam on unpolarized target
- Mokeev et al. (solid, dotted)
- Fix and Arenhövel (dashed)
Polarization Experiments in 2006

CLAS, JLab

GRAAL

Crystal Ball, Mainz

Crystal Barrel, Bonn
The FROST Program at CLAS

- Search for Missing Nucleon Resonances in the Photoproduction of Hyperons using Polarized Photon Beam and Polarized Target
- Pion Production From a Polarized Target
- Helicity Structure of Pion Photoproduction
- Measurement of Polarization Observables in $\eta$ Photoproduction
- Measurement of $\pi^+\pi^-$ Photoproduction in Double-Polarization Experiments (to be submitted to PAC 29 next Monday)
Model Calculations of $P_y$ (new) by W. Roberts

$\phi \approx 0$, $\phi = 0.56 \text{ rad}$, $\phi = 2.09 \text{ rad}$, $\phi \approx \pi$

$\gamma p \rightarrow p\pi^+\pi^-$

Circ. Beam $\rightarrow$ Trans. Target
(target pol. $\perp$ reaction plane)

$D_{13}(1520) \rightarrow \Delta\pi$

- $g_1 = -0.4698$ (solid)
- $g_2 = -3.336$
- $g_1 = 0$ (dot-dashed)
- $g_2 = 0$ (dashed)

$W = 2 \text{ GeV}$

Invariant $p\pi^+$ mass [GeV/$c^2$]
Model Calculations of $P^s_z$ (known as G) by W. Roberts

$\phi \approx 0, \quad \phi = 0.56 \text{ rad}, \quad \phi = 2.09 \text{ rad}, \quad \phi \approx \pi$

$\gamma p \rightarrow p \pi^+ \pi^-$

Lin. Beam $\rightarrow$ Long. Target

$D_{13}(1520) \rightarrow \Delta \pi$

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Invariant $p\pi^+$ mass [GeV/$c^2$]
Model Calculations of $P_{c}^{Z} (\text{new})$ by W. Roberts

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Invariant $p\pi^{+}$ mass [GeV/$c^2$]
The CB-ELSA Polarization Program ($E_\gamma \leq 3.0$ GeV)

Advantage: **Very good Neutral-Particle Detection**

Proposals submitted to ELSA/MAMI PAC-05/September 2005

1. ELSA/1-2005  G in single $\pi^0$ and $\eta$ production
2. ELSA/2-2005  Helicity Dependence in Single $\pi^0/\eta$ Production
3. ELSA/3-2005  $\Sigma$ and G in $\eta$ photoproduction off Neutron
4. ELSA/4-2005  Beam-Target Asymmetries in $\omega$ Photoproduction
5. ELSA/5-2005  Meson-Nucleus Bound States
6. ELSA/6-2005  Double Polarization in $2\pi^0$ Photoproduction
7. ELSA/7-2005  Helicity Difference in $\pi^0\eta$ Photoproduction
Sensitivity of Observable $P_z^\circ$ (or E) to Resonances

- Best Solution
- No $N(2100)P_{11}$
- No $\Delta(1940)D_{33}$

Mass Region: 2000-2200 MeV/$c^2$

⇒ Effects are big ...
Bonher model: residual short-range interaction based on instanton-induced forces

Combined Analysis: CLAS and Crystal Barrel

For example:

\[ \gamma p \rightarrow p \pi^+ \pi^- \text{ at CLAS} \]

\[ \gamma p \rightarrow p \pi^0 \pi^0 \text{ at CB-ELSA} \]

Not Competitors  ⇒  Complementary
Fruitful Discussions at NSTAR 2005 in Tallahassee!
Next NSTAR Workshop: Bonn, Germany in 2007!