Search for new Baryon States at ELSA

Volker Credé

Florida State University
Tallahassee, FL

Narrow Nucleon Resonances:
Predictions, Evidences, Perspectives

Edinburgh, June 9th, 2009
Outline

1. Introduction

2. Photoproduction of a Single Pseudoscalar Meson
   - $\eta$ Photoproduction (off the Proton)
   - $\eta'$ Photoproduction
   - $\pi^0$ Photoproduction (in the Forward Direction)

3. Toward Complete Experiments
   - What do we need?

4. Summary and Outlook
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3 Toward Complete Experiments
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4 Summary and Outlook
One of the Main Goals of the $N^*$ Program...

Search for *missing* or yet unobserved resonances

Quark models predict many more baryons than have been observed

<table>
<thead>
<tr>
<th>N Spectrum</th>
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<tr>
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<td>11</td>
<td>3</td>
<td>6</td>
<td>2</td>
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<td>$\Delta$ Spectrum</td>
<td>7</td>
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</table>

⇒ 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!!
One of the Main Goals of the $N^*$ Program ...

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   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!!
Possible Quark-Diquark Structure?

Regge trajectory for $\Delta^*$ states with intrinsic spin $S = 1/2$ and $S = 3/2$, and for $N^*$ states with spin $S = 3/2$ ($M^2$ versus $L$, not $J$)

- Common Regge trajectory for $N/\Delta$ states with $S = 3/2$
- Not shown, but slope of the Regge trajectory for meson and $\Delta$ excitations is identical
- Are baryons quark-diquark excitations?
Introduction
Photoproduction of a Single Pseudoscalar Meson
Toward Complete Experiments
Summary and Outlook

Nucleon Resonances: Status of 2001

many predicted states missing

P_{11}(1986)

S_{11}(1900)

D_{13}(1895)
(CLAS: m \approx 1910)

OGE Model: residual short-range interaction based on one-gluon exchange

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Search for new Baryon States at ELSA
**Introduction**

Photoproduction of a Single Pseudoscalar Meson
Toward Complete Experiments

**Summary and Outlook**

**Reaction Thresholds**

- $\gamma p \rightarrow p\eta\eta$
- $\gamma p \rightarrow p\pi^0\omega$
- $\gamma p \rightarrow p\pi^0\eta$
- $\gamma p \rightarrow p\eta$
- $\gamma p \rightarrow p\pi\pi$
- $\gamma p \rightarrow p\pi$
- $\gamma p \rightarrow p\pi$

*In addition:*

- LEGS
- SPring-8

**Partially complementary**

- All facilities have started polarization programs

**E_\gamma [GeV]**

- 1.66
- 0.06
- 0.00

**W [GeV]**

- 3.0
- 2.0
- 1.0
- 0.0

**Values:**

- ELSA: 2.6
- CLAS: 2.6*
- MAMI-C: 1.9
- GRAAL: 1.7
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The CB-ELSA/TAPS Experiment

- (un)polarized beam
- liquid H₂, deuterium
- solid targets

TAPS
- 512 BaF Crystals
- Forward detector
  - High Granularity
  - Fast Trigger

Goniometer
- amorphous radiators
- screen
- empty position
- wires for determination of beam profiles
- diamond crystal
CB-ELSA/TAPS Experimental Setup of 2002/2003

**Tagged Photons \( (E_{e^-} = 3.2 \text{ GeV}) \)**

- 14 counters + 2 wire chambers
- \( 0.25 \cdot E_{e^-} \leq E_{\gamma} \leq 0.95 \cdot E_{e^-} \)
- \( 800 \text{ MeV} \leq E_{\gamma} \leq 3000 \text{ MeV} \)

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Search for new Baryon States at ELSA
Study of $\gamma p \rightarrow p \eta$ with CB-ELSA/TAPS

\[ \gamma p \rightarrow p X \text{ (missing mass)} \]  
(CLAS)

\{ $\eta \rightarrow 3\pi^0, \gamma\gamma$  
(CB-ELSA/TAPS) \}

M. Dugger et al., PRL 89, 222002 (2002)
Study of $\gamma p \rightarrow p\eta$ with CB-ELSA/TAPS

Reconstruction
- Number of photons: $N_\gamma = 2, 6$
- Proton identification: TAPS and inner scintillating fibre detector
  - Missing proton kinematic fit
- Data quality
  - 422,300 events for $\eta \rightarrow \gamma\gamma$: $\sigma \approx 13$ MeV
  - 126,300 events for $\eta \rightarrow 3\pi^0$: $\sigma \approx 10$ MeV
Study of $\gamma p \rightarrow \rho \eta$ (2008 Data from CB-ELSA/TAPS)

- Full angular coverage
- Absolute normalization

V.C. et al. [CB-ELSA Collaboration], PRL D94, 012004 (2005)
Study of $\gamma p \rightarrow p \eta$ (2008 Data from CB-ELSA/TAPS)

V.C. et al. [CB-ELSA Collaboration], PRL D94, 012004 (2005)
Study of $\gamma p \rightarrow \rho \eta$ (2008 Data from CB-ELSA/TAPS)

V.C. et al. [CB-ELSA Collaboration], PRL D94, 012004 (2005)
Analysis of $\gamma p \rightarrow p\eta$: Total Cross Section

Isospin Filter
$\Rightarrow$ Only $N^*$ resonances can contribute!

Bonn-Gatchina (PWA) group:
Hint for $N^*$ resonance $(2070)D_{15}$

Three resonances are dominantly contributing:
$N(1535)S_{11}$, $N(1720)P_{13}$, $N(2070)D_{15}$
Partial Wave Analysis: $\gamma p \rightarrow p\eta$

**PWA:** Operator (Tensor) Formalism (Rarita–Schwinger)

- Many data sets included
- Cross section data and polarization observables
- Solutions not unique

<table>
<thead>
<tr>
<th>Observables</th>
<th>Reference</th>
<th>$N_{\text{data}}$</th>
<th>$\chi^2/N$</th>
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<tbody>
<tr>
<td>$\sigma(\gamma p \rightarrow p\eta)$</td>
<td>CB-ELSA</td>
<td>667</td>
<td>0.91</td>
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<td>$\sigma(\gamma p \rightarrow p\eta)$</td>
<td>TAPS</td>
<td>100</td>
<td>1.6</td>
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<td>$\Sigma(\gamma p \rightarrow p\eta)$</td>
<td>GRAAL 98</td>
<td>51</td>
<td>2.27</td>
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<td>GRAAL 04</td>
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<td>$\sigma(\gamma p \rightarrow p\pi^0)$</td>
<td>CB-ELSA</td>
<td>1106</td>
<td>1.50</td>
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<td>$\Sigma(\gamma p \rightarrow p\pi^0)$</td>
<td>GRAAL 04</td>
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<td>$\Sigma(\gamma p \rightarrow p\pi^0)$</td>
<td>SAID</td>
<td>593</td>
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<td>$\sigma(\gamma p \rightarrow n\pi^+)$</td>
<td>SAID</td>
<td>1583</td>
<td>2.86</td>
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<table>
<thead>
<tr>
<th>Resonance</th>
<th>$M$ (MeV)</th>
<th>$\Gamma$ (MeV)</th>
<th>Fraction</th>
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<tbody>
<tr>
<td>N(1520)D$_{13}$</td>
<td>1523 ± 4</td>
<td>105$^{+6}_{-18}$</td>
<td>0.020</td>
</tr>
<tr>
<td>PDG</td>
<td>1520$^{+10}_{-5}$</td>
<td>120$^{+15}_{-10}$</td>
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<tr>
<td>N(1535)S$_{11}$</td>
<td>1501 ± 5</td>
<td>215 ± 25</td>
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<tr>
<td>PDG</td>
<td>1505 ± 10</td>
<td>170 ± 80</td>
<td>0.430</td>
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<tr>
<td>N(1610)S$_{11}$</td>
<td>1610 ± 10</td>
<td>190 ± 20</td>
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<tr>
<td>PDG</td>
<td>1660 ± 20</td>
<td>160 ± 10</td>
<td></td>
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<tr>
<td>N(1675)D$_{15}$</td>
<td>1690 ± 12</td>
<td>125 ± 20</td>
<td>0.001</td>
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<tr>
<td>PDG</td>
<td>1675$^{+10}_{-5}$</td>
<td>150$^{+30}_{-10}$</td>
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<tr>
<td>N(1680)F$_{15}$</td>
<td>1669 ± 6</td>
<td>85 ± 10</td>
<td>0.005</td>
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<tr>
<td>PDG</td>
<td>1680$^{+10}_{-5}$</td>
<td>130 ± 10</td>
<td></td>
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<tr>
<td>N(1700)D$_{13}$</td>
<td>1740 ± 12</td>
<td>84 ± 16</td>
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<tr>
<td>PDG</td>
<td>1700 ± 50</td>
<td>100 ± 50</td>
<td></td>
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<tr>
<td>N(1720)P$_{13}$</td>
<td>1775 ± 18</td>
<td>325 ± 25</td>
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<tr>
<td>PDG</td>
<td>1720$^{+30}_{-70}$</td>
<td>250 ± 50</td>
<td></td>
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<tr>
<td>N(2000)F$_{15}$</td>
<td>1950 ± 25</td>
<td>230 ± 45</td>
<td>0.007</td>
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<td>N(2070)D$_{15}$</td>
<td>2068 ± 22</td>
<td>295 ± 40</td>
<td>0.171</td>
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<td>N(2080)D$_{13}$</td>
<td>1943 ± 17</td>
<td>82 ± 20</td>
<td>0.011</td>
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<tr>
<td>N(2200)P$_{13}$</td>
<td>2214 ± 28</td>
<td>360 ± 55</td>
<td>0.051</td>
</tr>
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</table>

*K-Matrix Fit,
Fraction for the total K-matrix contribution

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Search for new Baryon States at ELSA
Analysis of $\gamma p \rightarrow p\eta$: Total Cross Section

Isospin Filter

$\rightarrow$ Only $N^*$ resonances can contribute!

Bonn-Gatchina (PWA) group:

Hint for $N^*$ resonance $(2070)D_{15}$


1. Confirmed in 2009 analysis!

2. $N(1720)P_{13} \rightarrow p\eta$?

$\rightarrow$ $\eta$-MAID:

$N(1710)P_{11} \rightarrow p\eta$ significant!

Resonances dominantly contributing:

$N(1535)S_{11}, (N(1720)P_{13})?, N(2070)D_{15}$

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   $\rightarrow$ $\eta$-MAID: $N(1710)P_{11} \rightarrow p\eta$ significant!

$M \approx 1720$ MeV/c$^2$
Higher sensitivity due to interference effects: \( \Sigma \sim A_{1/2}(S_{11}) \ast A_{1/2}(P_{13}) + \ldots \)

D. Elsner et al., EPJ A33 (2007) 147

R. Beck, Talk at N* 2009
Study of $\gamma p \rightarrow p\eta'$ with CB-ELSA/TAPS

Isospin Filter: only $N^*$ resonances can contribute

1968: 11 events from the ABBHMM bubble chamber experiment
1976: 7 events from the AHHM streamer chamber experiment
1998: 250 events from SAPHIR collaboration

$\Rightarrow$ First differential cross sections

2006: over $2 \cdot 10^5$ events from CLAS
(Contributions from $N(1535)S_{11}$, $N(1710)P_{11}$, $J = 3/2$ states)

2008: New data from CBELSA/TAPS over the full angular range

No published asymmetry data for $\eta'$...
(Data available from CLAS and ELSA)
Photoproduction of a Single Pseudoscalar Meson
Toward Complete Experiments

Summary and Outlook

η Photoproduction (off the Proton)
η’ Photoproduction
π^0 Photoproduction (in the Forward Direction)

Linearly-Polarized Beam at JLab: g8b Run Group

\[ \frac{d\sigma}{d\Omega} \text{ for } \gamma p \rightarrow \eta' p \]

Analysis of \( \gamma p \rightarrow p\eta' \)

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Search for new Baryon States at ELSA
Study of $\gamma p \rightarrow p \eta'$ with CB-ELSA/TAPS

Reconstruction of $\eta'$:
- Kinematic Fitting to $\gamma p \rightarrow p \pi^0 \eta \gamma \gamma$
- Mass window for remaining $\pi^0$:
  $110 < m_{\gamma \gamma} < 160$ MeV
- Mass window for $\eta'$:
  $910 < m_{\pi^0 \pi^0 \eta} < 1010$ MeV

$\pi^0 \eta$ ($\gamma \gamma$)
$\pi^0 \pi^0$ ($\gamma \gamma$)
Differential Cross Sections for $\gamma p \rightarrow p\eta'$

- CB-ELSA/TAPS
- SAPHIR
- CLAS
- SAID
- BoGA

Preliminary
Study of $\gamma p \rightarrow p\eta'$ Threshold

--- CBELSA/TAPS

$\frac{d\sigma}{d\Omega}$ [µb/sr]

$\cos \theta$ (cms)

Preliminary
Threshold Behavior of $\gamma p \rightarrow \rho \eta'$

This analysis: $E_\gamma = (1442.6 \pm 3.80) \text{ MeV}$

PDG: $E_\gamma = (1446.4 \pm 0.48) \text{ MeV}$

Preliminary
Introduction

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η′ Photoproduction

π^0 Photoproduction (in the Forward Direction)

Threshold Behavior of $\gamma p \rightarrow p\eta'$

This analysis: $E_\gamma = (1442.6 \pm 3.80)\,\text{MeV}$

PDG: $E_\gamma = (1446.4 \pm 0.48)\,\text{MeV}$

Conclusion

η′ Threshold dominated by S-wave

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Search for new Baryon States at ELSA
Differential Cross Sectionss for $\gamma p \rightarrow p\pi^0$

--- CBELSA/TAPS --- CB-ELSA --- SAID --- BoGa


Search for new Baryon States at ELSA
Differential Cross Sections for $\gamma p \rightarrow p\pi^0$
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Preliminary
Differential Cross Sections for $\gamma p \rightarrow p\pi^0$

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Beam Asymmetries for $\gamma p \rightarrow p\pi^0$

--- CBELSA/TAPS New --- CBELSA/TAPS --- GRAAL --- SAID


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Search for new Baryon States at ELSA

Preliminary
Beam Asymmetries for $\gamma p \rightarrow p\pi^0$

--- CBELSA/TAPS New  --- CBELSA/TAPS  --- GRAAL  --- SAID

$E = 1064, \theta = 25^\circ$

$E = 1295, \theta = 35^\circ$


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Beam Asymmetries for $\gamma p \rightarrow p\pi^0$


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Search for new Baryon States at ELSA
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Preliminary
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### (New) Baryon Resonances: Bonn-Gatchina PWA

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<td>$\Delta(1232)P_{33}$, $N(1520)D_{13}$, $N(1680)F_{15}$, $N(1535)S_{11}$</td>
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<td>$\gamma p \rightarrow p\pi^0\pi^0$</td>
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<tr>
<td>$\gamma p \rightarrow p\pi^0\eta$</td>
<td>$\Delta(1940)D_{33}$, $\Delta(1920)P_{33}$, $N(2200)P_{13}$, $\Delta(1700)D_{33}$</td>
</tr>
<tr>
<td>$\gamma p \rightarrow \Lambda K^+$</td>
<td>$S_{11}$ – wave, $N(1720)P_{13}$, $N(1900)P_{13}$, $N(1840)P_{11}$</td>
</tr>
<tr>
<td>$\gamma p \rightarrow \Sigma K$</td>
<td>$S_{11}$ – wave, $N(1900)P_{13}$, $N(1840)P_{11}$</td>
</tr>
<tr>
<td>$\pi^- p \rightarrow n\pi^0\pi^0$</td>
<td>$N(1440)P_{11}$, $N(1520)D_{13}$, $S_{11}$ – wave</td>
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The available data sets comprising various high-statistics differential cross sections, beam, target, recoil asymmetries, double polarization observables, and also data resolving isospin contributions are not yet sufficient to converge into a unique solution.
Ingredients

- Measurements off neutron and proton to resolve isospin contributions
  1. $A(\gamma N \rightarrow \pi, \eta, K)^I=3/2 \iff \Delta^*$
  2. $A(\gamma N \rightarrow \pi, \eta, K)^I=1/2 \iff N^*$

- Re-scattering effects: Large number of measurements (and also final states) needed to define the full scattering amplitude

- Double-polarization measurements


In order to determine the full scattering amplitude without ambiguities, one has to carry out eight carefully selected measurements: four double-spin observables along with the four single-spin observables.
Helicity-Dependent Cross Section: $\vec{\gamma} \vec{p} \rightarrow \rho \eta$

Preliminary results (M. Gottschall)

$N_{1/2} - N_{3/2}$

$S_{11}(1535)$

$P_{11}(1710)$

$P_{33}(1720)$

$\sigma_{1/2} - \sigma_{3/2}$
Helicity-Dependent Cross Section: $\vec{\gamma} \vec{p} \rightarrow p \eta$
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Search for new Baryon States at ELSA
Photoproduction of neutral mesons with the CBELSA/TAPS detector

- Full angular coverage for $\eta$ and $\eta'$ production
  - Confirmation of $D_{15}(2070) \rightarrow p\eta$
- No evidence for narrow state at $M \approx 1685$ MeV/$c^2$
- Excellent coverage for the $\pi^0$ in the very forward direction
- Contributions for new results from
  Aaron McVeigh, Nathan Sparks, Anna Woodard
Summary and Outlook

Photoproduction of neutral mesons with the CBELSA/TAPS detector

- Full angular coverage for $\eta$ and $\eta'$ production
  ➔ Confirmation of $D_{15}(2070) \rightarrow p\eta$
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HADRON 2009
Nov. 29 - Dec. 4
Tallahassee, Florida
Florida State University