Status of and Prospects for N* Spectroscopy

Volker Credé

Florida State University
Tallahassee, FL

Lattice QCD and Experiment

Jefferson Laboratory, 11/21/2008

Outline

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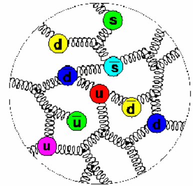
1. Introduction
2. Status
   - η (η') Photoproduction
   - Double-Pion
   - Hyperon Photoproduction
3. Towards Complete Experiment
   - Ingredients
   - Polarization
4. Summary and Outlook

$\ll 0.1$ fm

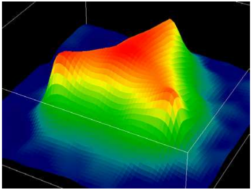


pQCD

q, g, q$\bar{q}$

! ? ↔ ? !

0.1 – 1.0 fm

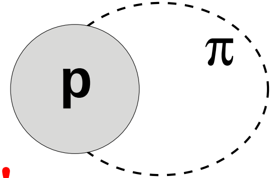


Models

Quarks and Gluons as Quasiparticles

? ! ↔ ! ?

> 1.0 fm



ChPT

Nucleon and Mesons

1. What are the relevant degrees of freedom?
2. What are the corresponding effective interactions responsible for hadronic phenomena?

The Excited Baryon Program at JLab

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

Outline

One of the Main Goals of the N^* Program ...

Search for *missing* resonances

Quark models predict many more baryons than have been observed

	****	***	**	*
N Spectrum	11	3	6	2
Δ Spectrum	7	3	6	6

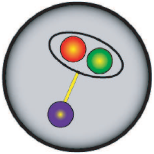
$\Rightarrow$ according to PDG

Phys. Rev. **D66** (2002) 010001

$\Rightarrow$ 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 πN scattering experiments

➜ If the missing resonances did not couple to Nπ, they would not have been discovered!!

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Phys. Lett. B **667**, 1 (2008)
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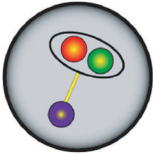

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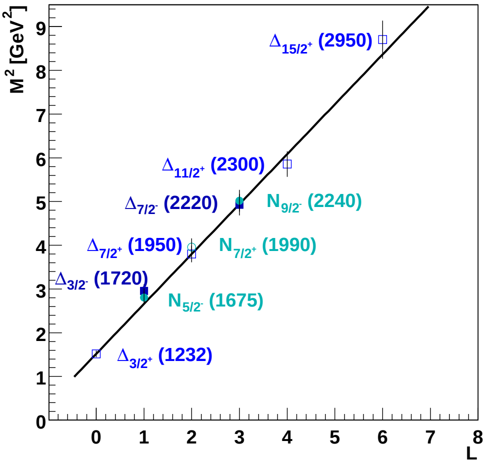
Possible Quark-Diquark Structure?



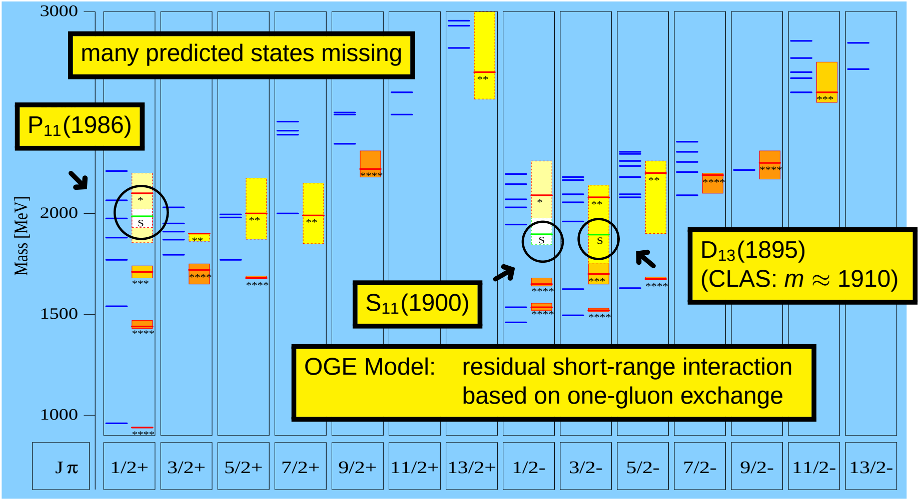
Regge trajectory for Δ^* states with intrinsic spin $S = 1/2$ and $S = 3/2$, and for N^* states with spin $S = 3/2$ (M^2 versus L, not J)

1. Common Regge trajectory for N/Δ states with $S = 3/2$
2. Not shown, but slope of the Regge trajectory for meson and Δ excitations is identical

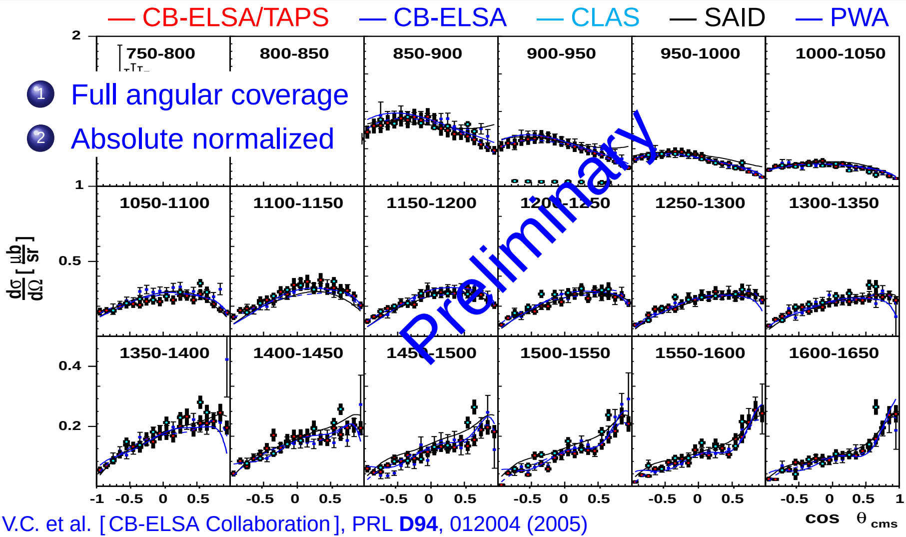
➜ Are baryons quark-diquark excitations?

Nucleon Resonances: Status – 2001

—— S. Capstick and N. Isgur, Phys. Rev. **D34** (1986) 2809



Analysis of $\gamma p \rightarrow p\,\eta$ (New Data from CB-ELSA/TAPS)



1. Full angular coverage
2. Absolute normalized

V.C. et al. [CB-ELSA Collaboration], PRL **D94**, 012004 (2005)

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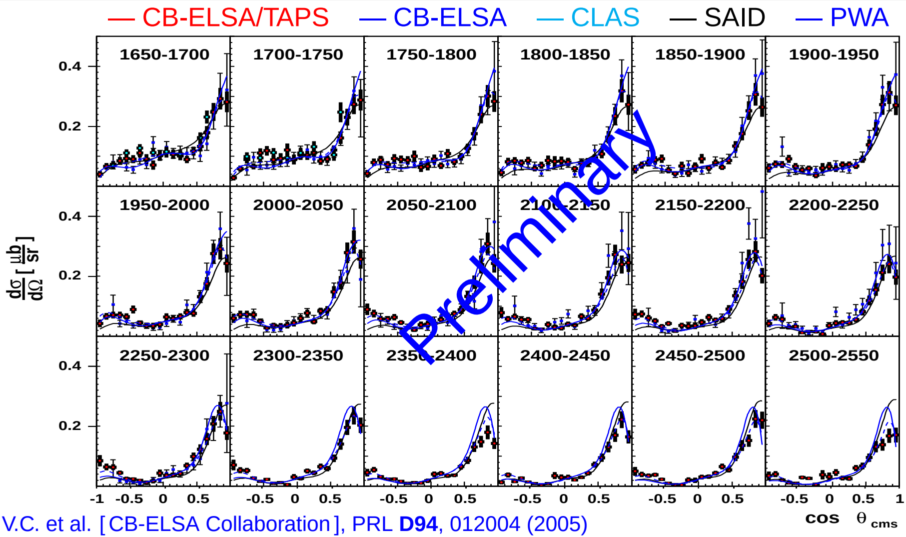
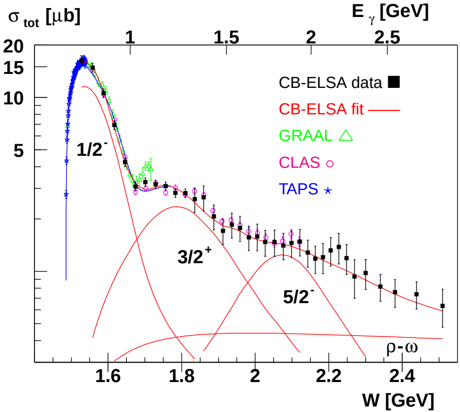


V.C. et al. [CB-ELSA Collaboration], PRL **D94**, 012004 (2005)

Analysis of $\gamma p \rightarrow p\,\eta$: Total Cross Section



Isospin Filter

➜ Only N* resonances can contribute!

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

(Phys. Rev. Lett. **D94**, 012004 (2005))

Three resonances are dominantly contributing!

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

Partial Wave Analysis (PWA Center at ELSA)

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

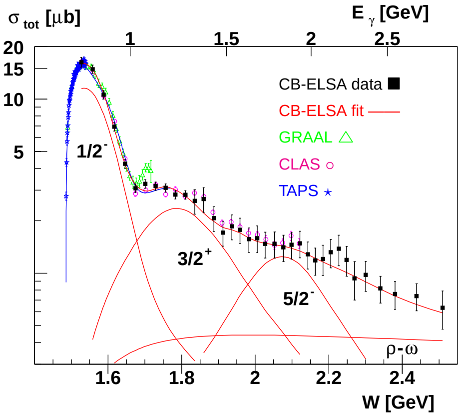
- Datasets

Observables	Reference	N_{data}	χ^2/N
$\sigma(\gamma p \to p\eta)$	CB-ELSA	667	0.91
$\sigma(\gamma p \to p\eta)$	TAPS	100	1.6
$\Sigma(\gamma p \to p\eta)$	GRAAL 98	51	2.27
$\Sigma(\gamma p \to p\eta)$	GRAAL 04	100	1.75
$\sigma(\gamma p \to p\pi^0)$	CB-ELSA	1106	1.50
$\Sigma(\gamma p \to p\pi^0)$	GRAAL 04	469	3.43
$\Sigma(\gamma p \to p\pi^0)$	SAID	593	2.87
$\sigma(\gamma p \to n\pi^+)$	SAID	1583	2.86

Resonance	M (MeV)	Γ (MeV)	Fraction
$N(1520)D_{13}$	1523 ± 4	105^{+6}_{-18}	0.020
PDG	1520^{+10}_{-5}	120^{+15}_{-10}	
$N(1535)S_{11}$ *	1501 ± 5	215 ± 25	0.430
PDG	1505 ± 10	170 ± 80	
$N(1650)S_{11}$ *	1610 ± 10	190 ± 20	
PDG	1660 ± 20	160 ± 10	
$N(1675)D_{15}$	1690 ± 12	125 ± 20	0.001
PDG	1675^{+10}_{-5}	150^{+30}_{-10}	
$N(1680)F_{15}$	1669 ± 6	85 ± 10	0.005
PDG	1680^{+10}_{-5}	130 ± 10	
$N(1700)D_{13}$	1740 ± 12	84 ± 16	0.004
PDG	1700 ± 50	100 ± 50	
$N(1720)P_{13}$	1775 ± 18	325 ± 25	0.300
PDG	1720^{+30}_{-70}	250 ± 50	
$N(2000)F_{15}$	1950 ± 25	230 ± 45	0.007
$N(2070)D_{15}$	2068 ± 22	295 ± 40	0.171
$N(2080)D_{13}$	1943 ± 17	82 ± 20	0.011
$N(2200)P_{13}$	2214 ± 28	360 ± 55	0.051

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

Analysis of $\gamma p \to p\,\eta$: Total Cross Section



Isospin Filter

➜ Only N* resonances can contribute!

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

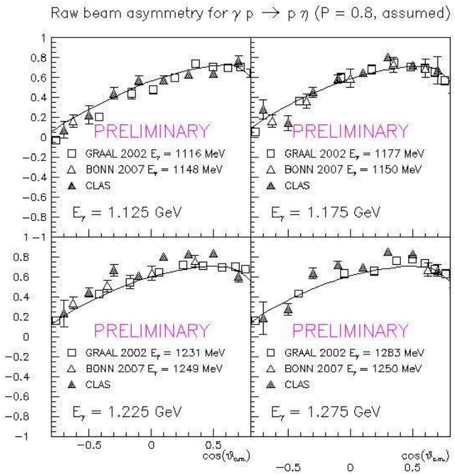
(Phys. Rev. Lett. **D94**, 012004 (2005))

1. Confirmed in new analysis!
2. N(1720)$P_{13} \to \eta$ p unexpected
   ➜ η-MAID:
   N(1710)$P_{11} \to \eta$ p significant!

Three resonances are dominantly contributing!

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

Linearly-Polarized Beam at JLab: $\Sigma(\gamma p \to p\,\eta)$



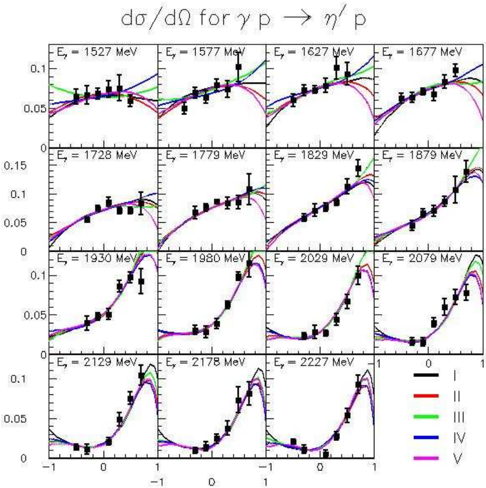
Good agreement with other data

- Interpretation of Bonn (PWA) and CLAS data (SAID) different: $P_{13}(1720) \Leftrightarrow P_{11}(1710)$

Preliminary analysis of $\gamma p \to p\eta$
(Mike Dugger, ASU)

- P_γ estimated at 0.8
- — SAID prediction
- Data with statistical errors (no systematic)

Linearly-Polarized Beam at JLab: g8b Run Group



Set IV

N(1535)S_{11}, N(2090)S_{11}

N(1710)P_{11}, N(2100)P_{11}

N(1700)D_{13}, N(2080)D_{13}

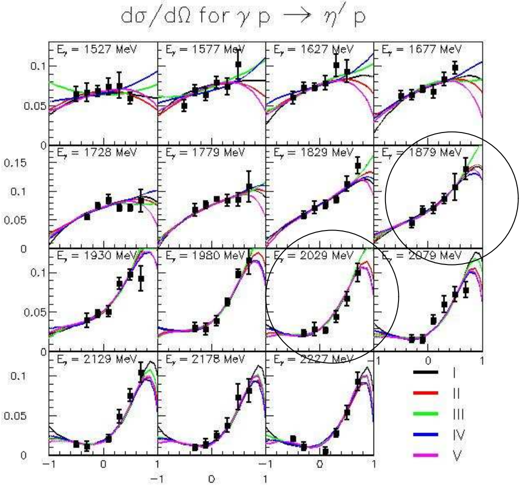
Similar to η analysis:

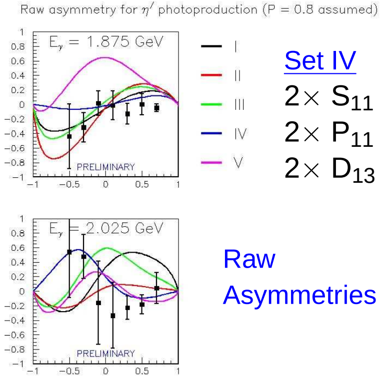
N(1535)S_{11} and N(1710)P_{11} dominant (SAID, MAID)!

Analysis of $\gamma p \to p\eta'$

Phys. Rev. Lett. **96**, 062001 (2006)

Linearly-Polarized Beam at JLab: g8b Run Group





Set IV

$2\times$ S_{11}

$2\times$ P_{11}

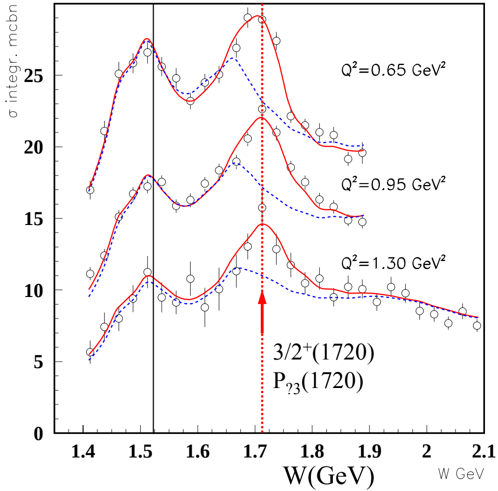
$2\times$ D_{13}

Raw Asymmetries

Analysis of $\gamma p \to p\eta'$

Phys. Rev. Lett. **96**, 062001 (2006)

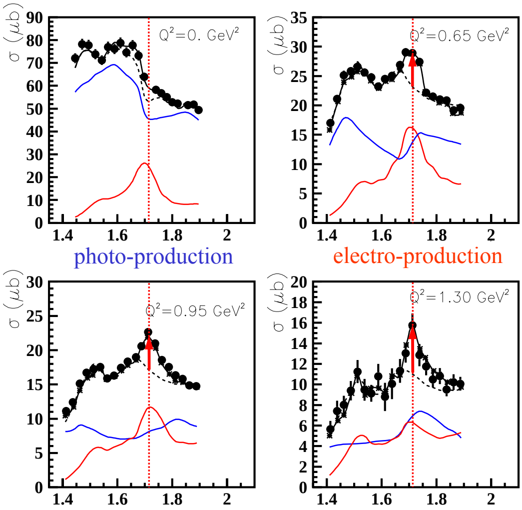
Resonances in $\gamma^{(*)}p \to p\pi^+\pi^-$



- 2π channel sensitive to N^*'s heavier than 1.4 GeV
- Provides complementary information to the 1π 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 ?(1720)$P_{?3}$ state

Resonances in $\gamma^{(*)}p \to p\pi^+\pi^-$



- Background
- Resonances

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

Fit needs both the candidate ?(1720)$P_{?3}$ and the N(1720)P_{13} state.

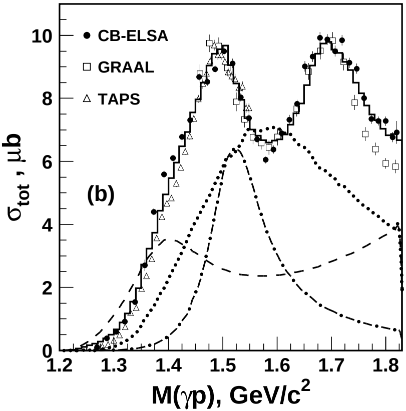
Authors claim that combined fit of various single differential cross sections allowed to establish all significant mechanisms.

Reasonable Description of Nπ/N$\pi\pi$ Electroproduction

The CLAS-Collaboration phenomenological models (UIM/DR/JM) reproduce reasonably well comprehensive CLAS/world data on all observables in Nπ/N$\pi\pi$ electroproduction:

- Isobars used in N$\pi\pi$ electroproduction
  1. All well-established $\mathrm{N}^* \to \pi^-\Delta^{++}$ decays + $3/2^+$(1720)
  2. All well-established $\mathrm{N}^* \to \rho\pi$ decays + $3/2^+$(1720)
  3. Observed for the first time in CLAS data: $\pi^+\mathrm{D}^0_{13}$(1520), $\pi^+\mathrm{F}^0_{15}$(1685), and $\pi^-\mathrm{P}^{++}_{33}$(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. C**76**, 065201 (2007))

Total Cross Section for $\gamma p \rightarrow p\pi^0\pi^0$ (CB-ELSA)



Event-based Maximum Likelihood Fit

- N(1440)P_{11}, N(1520)D_{13}, N(1680)F_{15} Δ(1700)D_{33}, Δ(1920)P_{33}, Δ(1940)D_{33} ...

+ Background amplitudes

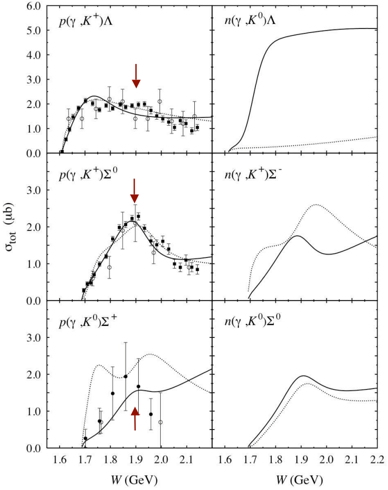
— · — · — N(1520)D_{13}

— — — — N(1440)P_{11}

· · · · · · Δ(1700)D_{33}

➜ Not compatible with N(1440)$P_{11} \rightarrow p\sigma$ dominance!

Baryon Resonances in Hyperon Photoproduction



p and n KY-Mart&Bennhold-hst06

Baryon Resonances in Hyperon Photoproduction

Outline

Title

. S. Barker, A. Donnachie and J. K. Storrow, Nucl. Phys. B **95**, 347 (1975).

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