Light Baryon Spectroscopy
What have we learned about excited baryons?

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The 19th Particles and Nuclei International Conference

MIT, Cambridge, USA, 07/27/2011

Outline

1. Introduction
   - Quarks, QCD, and Confinement
   - Why do we study excited baryons?
2. The Search for Undiscovered States
   - Meson Photo-Production Data
   - Complete Experiments
3. Experimental Status of N^* (Polarization) Program
   - Polarization Experiments
   - Hadron Structure with Electromagnetic Probes
4. Summary and Outlook

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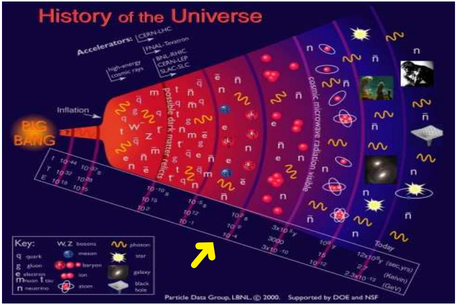
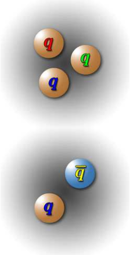
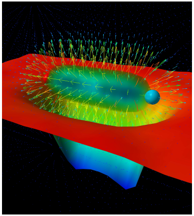
QCD and Confinement



From about 10^{-6} s on, all quark and anti-quarks became confined inside of hadronic matter. Only protons and neutrons remained after about 1 s.

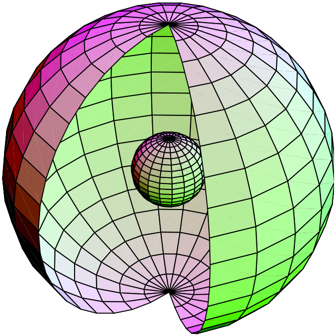




1. What is the origin of confinement?
2. How are confinement and chiral symmetry breaking connected?
3. Would the answers to these questions explain the origin of $\sim 99\,\%$ of observed matter?

Non-Perturbative QCD

Courtesy of Craig Roberts, Argonne



How does QCD give rise to hadrons?

Interaction between quarks unknown throughout > 98 % of a hadron's volume.

➜

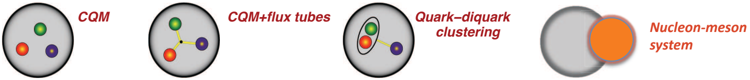
Explaining the excitation spectrum of hadrons is central to our understanding of QCD in the low-energy regime (Hadron Models, Lattice QCD, etc.)

➜ Complementary to Deep Inelastic Scattering (DIS) where information on collective degrees of freedom is lost.

The (Experimental) Issues with Hadrons

1. **Baryons**

   What are the fundamental degrees of freedom inside a proton or a neutron? How do they change with varying quark masses?



2. **Mesons**

   What is the role of glue in a quark-antiquark system and how is this related to the confinement of QCD?

   What are the properties of predicted states beyond simple quark-antiquark systems (hybrids, glueballs, multi-quark states, ...)?

➜ Need to map out new states (Session 3C):
BES III, BELLE, COMPASS, Panda@GSI, GlueX@JLab, ...

Components of the Experimental N^* Program

The excited baryon program has two main components:

- Establish the systematics of the spectrum
  Current medium-energy experiments use photon beams to map out the baryon spectrum (JLab, ELSA, MAMI, SPring-8, etc.).
  - ➜ Provides information on the nature of the effective degrees of freedom in strong QCD and also addresses the issue of previously unobserved or so-called *missing resonances.*
- Probe resonance transitions at different distance scales
  Electron beams are ideal to measure resonance form factors and their corresponding Q^2 dependence.
  - ➜ Provides information on the confining (effective) forces of the 3-quark system.

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

... is the search for *missing* or yet unobserved baryon resonances.

Quark models predict many more baryons than have been observed.

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

➜ Particle Data Group
(J. Phys. G **37**, 075021 (2010))

➜ little known
(many open questions left)

1. Are the states missing in the predicted spectrum because our models do not capture the correct degrees of freedom?
2. Or have the resonances simply escaped detection?

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... is the search for *missing* or yet unobserved baryon resonances.

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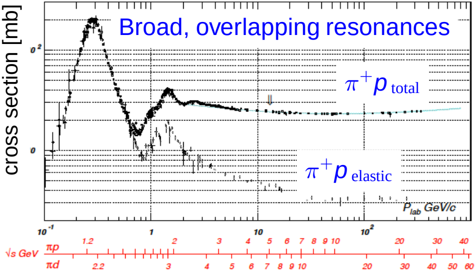


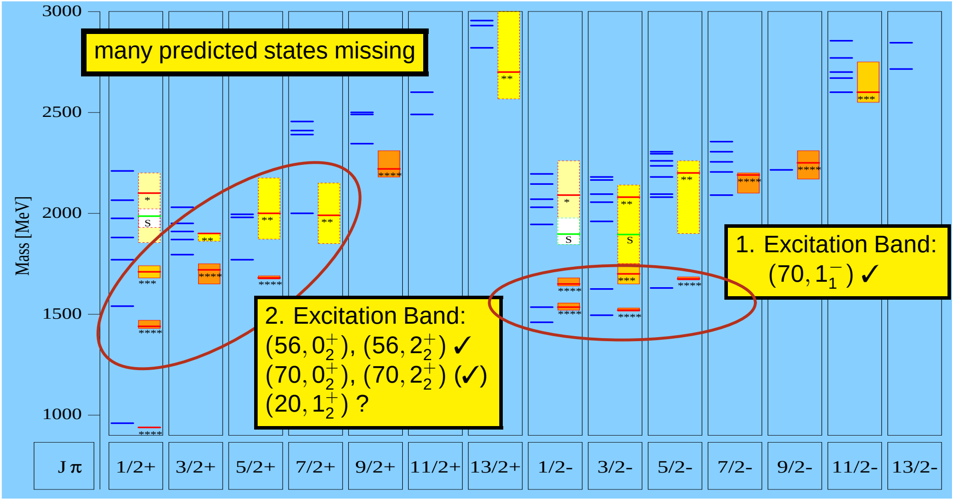
Have not been observed, yet.

Nearly all existing data on baryons result from πN scattering experiments.

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

Spectrum of Nucleon Resonances

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



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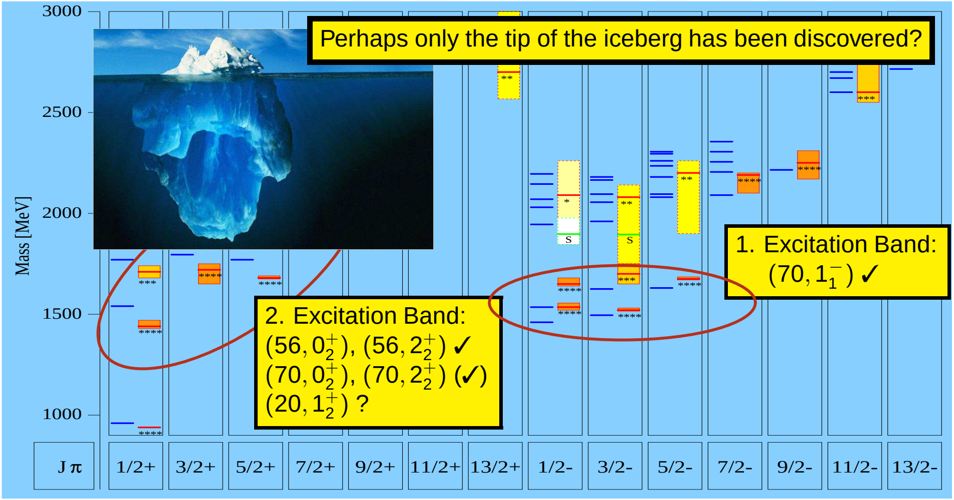
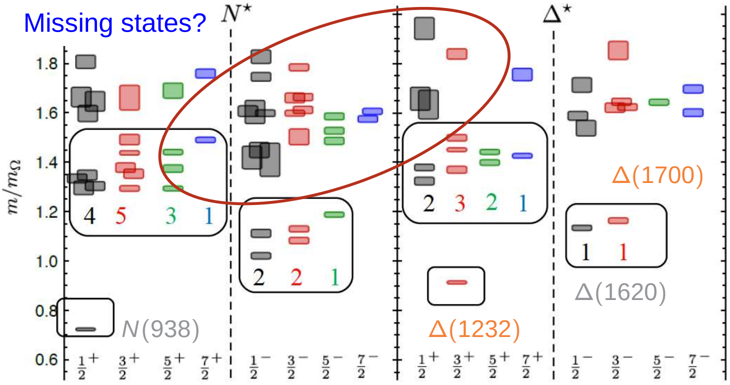


Excited-State Baryon Spectroscopy from Lattice QCD

R. Edwards *et al.*, arXiv:1104.5152 [hep-ph]

Missing states?



$m_\pi = 400$ MeV

C. Morningstar
➜ Session 2C

Exhibits broad features expected of $SU(6) \otimes O(3)$ symmetry

➜ Counting of levels consistent with non-rel. quark model, no parity doubling

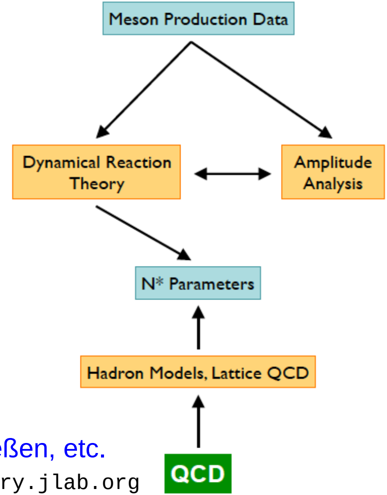
Extraction of Resonance Parameters

- Double-polarization measurements
- Measurements off neutron and proton to resolve isospin contributions:
  1. $\mathcal{A}(\gamma N \rightarrow \pi,\ \eta,\ K)^{I=3/2} \quad \Longleftrightarrow \quad \Delta^*$
  2. $\mathcal{A}(\gamma N \rightarrow \pi,\ \eta,\ K)^{I=1/2} \quad \Longleftrightarrow \quad N^*$
- Re-scattering effects: Large number of measurements (and reaction channels) needed to extract full scattering amplitude.

Coupled Channels

EBAC, Jülich, Gießen, etc.

`http://ebac-theory.jlab.org`



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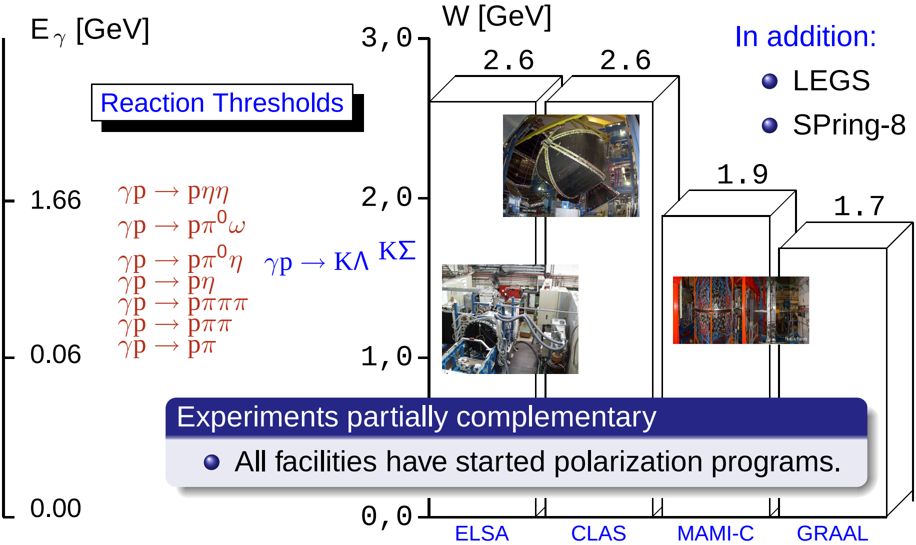


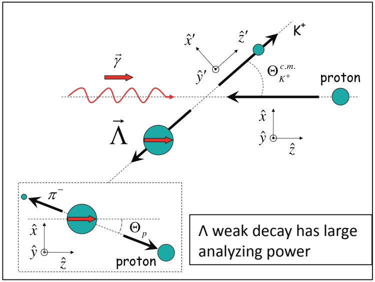
In addition:

- LEGS
- SPring-8

Experiments partially complementary

- All facilities have started polarization programs.

Complete Experiments in Photoproduction: $\gamma p \to K\ Y$



Chiang & Tabakin, Phys. Rev. C55, 2054 (1997)

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 four single-spin observables.

Eight well-chosen measurements are needed to fully determine the amplitude

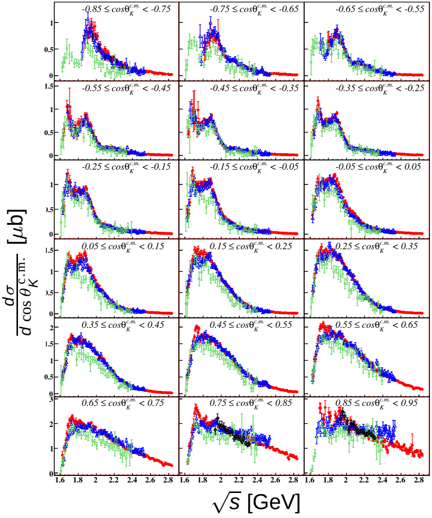
- 16 observables will be measured with CLAS
  ➜ Allows many cross checks

Photon beam		*Target*			*Recoil*			*Target - Recoil*								
					x'	y'	z'	x'	x'	x'	y'	y'	y'	z'	z'	z'
		x	y	z				x	y	z	x	y	z	x	y	z
unpolarized	σ_0		T			P		$T_{x'}$		$L_{x'}$		Σ		$T_{z'}$		$L_{z'}$
linearly P_γ	Σ	H	P	G	$O_{x'}$	T	$O_{z'}$	$L_{z'}$	$C_{z'}$	$T_{z'}$	E		F	$L_{x'}$	$C_{x'}$	$T_{x'}$
circular P_γ		F		E	$C_{x'}$		$C_{z'}$		$O_{z'}$		G		H		$O_{x'}$	

e.g. $\gamma p \to K\Lambda$

- ✓ published
- ✓ to be published
- ✓ data taken
- ✓ data taken, being analyzed

Comparison of Different Data for $\gamma p \to K^+ \Lambda$



Significant improvement of the data quality in recent years

- Much more precise data with larger kinematic coverage
- High-statistics data samples allow for many different topologies to be analyzed

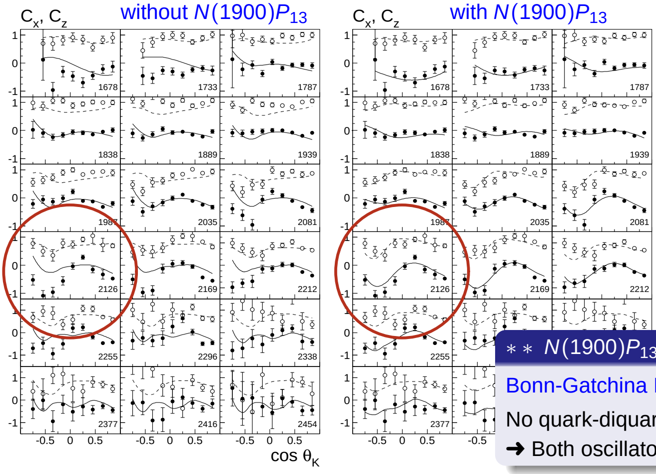
➜ Confirmation of CLAS '06 results

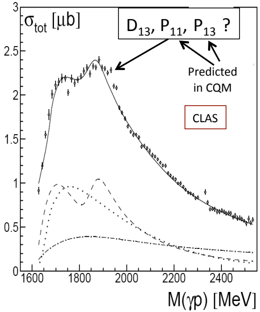
■ CLAS 2010
CLAS Collaboration, Phys. Rev. C **81**, 025201 (2010)

■ CLAS 2006
CLAS Collaboration, Phys. Rev. C **73**, 035202 (2006)

■ SAPHIR 2004
SAPHIR Collaboration, Eur. Phys. J. A **19**, 251 (2004)

Polarization Transfer in $\vec{\gamma} p \rightarrow K^+ \vec{\Lambda}$





$**$ $N(1900)P_{13}$, $N(2000)F_{15}$, $N(1990)F_{17}$

Bonn-Gatchina PWA requires $N(1900)P_{13}$.

No quark-diquark oscillations!

➜ Both oscillators need to be excited.

R. Bradford *et al.* [CLAS Collaboration], Phys. Rev. C **75**, 035205 (2007)

Fits: BoGa-Model, V. A. Nikonov *et al.*, Phys. Lett. B **662**, 245 (2008)

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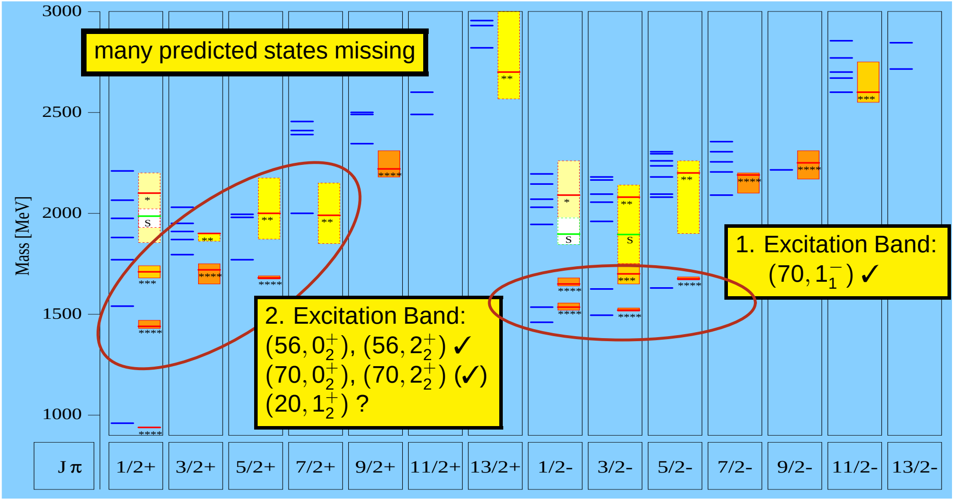
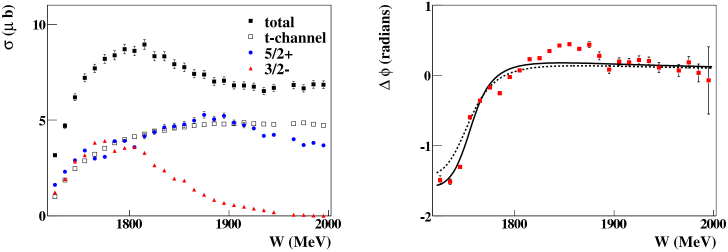


Isospin Filter: $\gamma p \to N^* \; (I = 1/2) \;\to p\,\omega$

M. Williams *et al.* [CLAS Collaboration], Phys. Rev. C **80**, 065209 (2009)



PWA fit includes resonances + *t*-channel amplitudes.

Strong evidence for ($W < 2$ GeV):

$(3/2)-$ N(1700) $***$

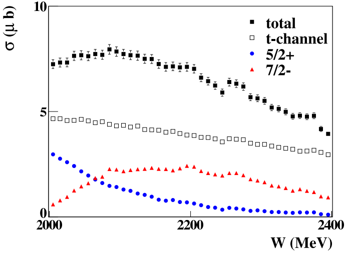
$(5/2)+$ N(1680) $****$

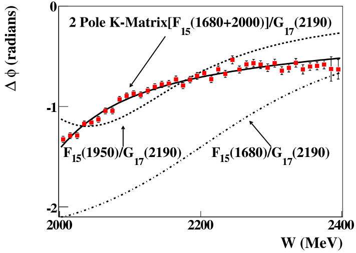
Only nucleon resonances can contribute (isospin filter)

- First-time PWA of ω photoproduction channel
- High statistics data sets are key to pull out signals.
  - ➜ CLAS at JLab can provide statistics, but there are also limitations in the acceptance.

Isospin Filter: $\gamma p \rightarrow N^* \; (I = 1/2) \; \rightarrow p\, \omega$

M. Williams *et al.* [CLAS Collaboration], Phys. Rev. C **80**, 065209 (2009)





PWA fit includes resonances + t-channel amplitudes.

Strong evidence for $(W > 2$ GeV):

$(5/2)+$ N(1680) $***\,*$

$(5/2)+$ N(1950) $**$

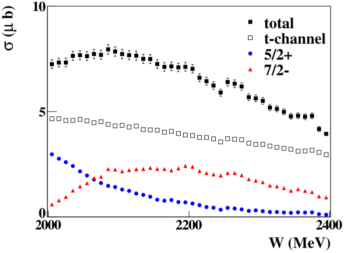
$(7/2)-$ N(2190) $***\,*$

Only nucleon resonances can contribute (isospin filter)

- First-time PWA of ω photoproduction channel
- High statistics data sets are key to pull out signals.
  - ➜ CLAS at JLab can provide statistics, but there are also limitations in the acceptance.
- Hints for a missing state!

Isospin Filter: $\gamma p \rightarrow N^* \; (I = 1/2) \; \rightarrow p\,\omega$

M. Williams *et al.* [CLAS Collaboration], Phys. Rev. C **80**, 065209 (2009)



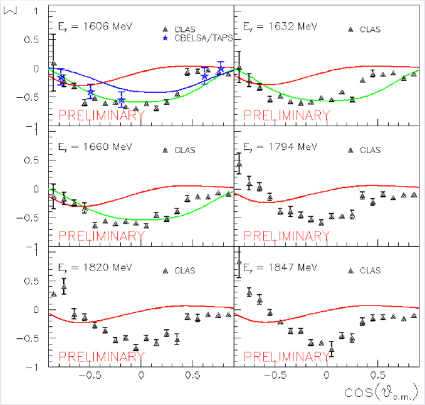
Strong evidence for ($W > 2$ GeV):

$(5/2)+$ N(1680) $****$

$(5/2)+$ N(1950) $**$

$(7/2)-$ N(2190) $****$

Asymmetry Σ for $\vec{\gamma} p \rightarrow p\,\omega$ (P. Collins *et al.*, CUA)

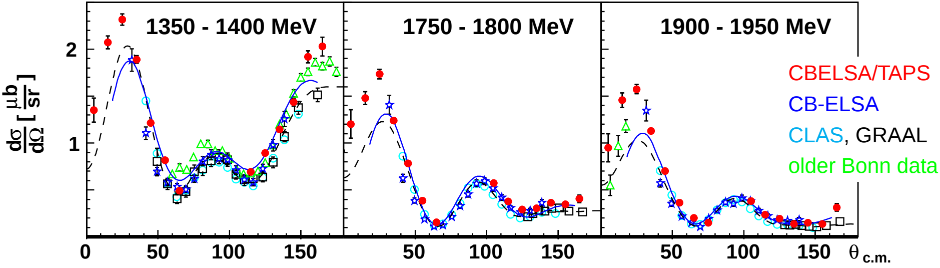


— Oh *et al.*
— Paris *et al.*
— Sarantsev *et al.*

Photoproduction of π^0 Mesons from the Proton

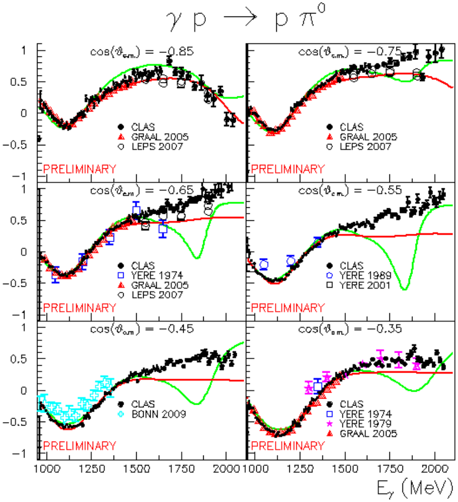
Reaction $\gamma p \to p\,\pi^0$ remains important for our understanding of baryons.

- At ELSA, excellent data with good statistics in the forward direction.
- Forward region is very sensitive to higher-spin resonances:
  ➜ Observation of $N(2190)G_{17}$ within the Bonn-Gatchina PWA framework
  (Important to confirm high-mass states first observed in πN scattering)



V. C. *et al.* [CBELSA/TAPS Collaboration], arXiv:1107.2151

Beam Asymmetry Σ in $\vec{\gamma} p \to p\,\pi^0$



$$\frac{d\sigma}{d\Omega} = \sigma_0 \{1 - \delta_l\, \Sigma \cos 2\phi$$
$$+ \Lambda_x\,(-\delta_l\, \mathbf{H} \sin 2\phi + \delta_\odot\, \mathbf{F})$$
$$- \Lambda_y\,(-\mathbf{T} + \delta_l\, \mathbf{P} \cos 2\phi)$$
$$- \Lambda_z\,(-\delta_l\, \mathbf{G} \sin 2\phi + \delta_\odot\, \mathbf{E})\}$$

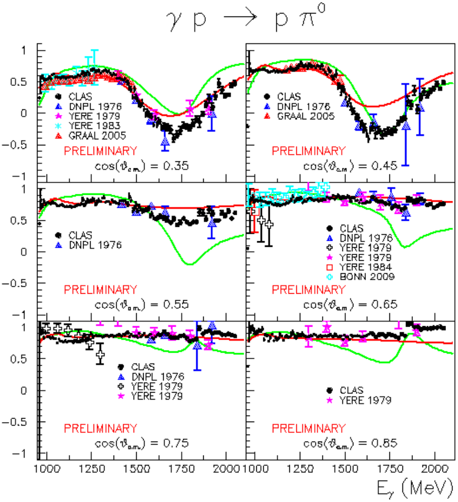
— SAID — MAID • CLAS

($E_\gamma < 2$ GeV, $-0.85 < \cos\theta_\pi < -0.35$)

➜ Serious discrepancies between models and data above 1.4 GeV.

M. Dugger (ASU), CLAS g8b run group, to be published

Beam Asymmetry Σ in $\vec{\gamma} p \rightarrow p\,\pi^0$



— SAID — MAID • CLAS
($E_\gamma < 2$ GeV, $0.35 < \cos\theta_\pi < 0.85$)

Combination of $p\,\pi^0$ and $n\,\pi^+$ final states can help distinguish between Δ and N^* resonances:

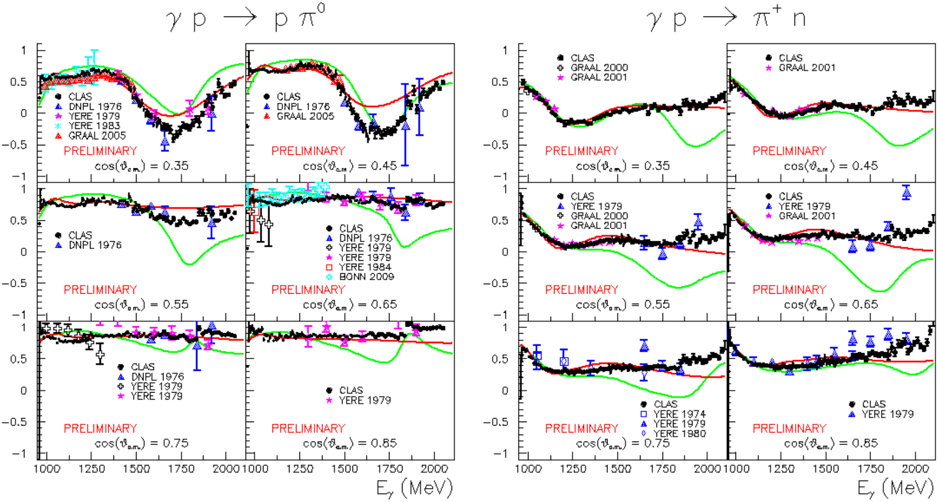
Δ^+ ↓ N^* ↓

$$\pi^0 + p : \sqrt{2/3}\left|I = \tfrac{3}{2}, I_3 = \tfrac{1}{2}\right\rangle - \sqrt{1/3}\left|I = \tfrac{1}{2}, I_3 = \tfrac{1}{2}\right\rangle$$

$$\pi^+ + n : \sqrt{1/3}\left|I = \tfrac{3}{2}, I_3 = \tfrac{1}{2}\right\rangle + \sqrt{2/3}\left|I = \tfrac{1}{2}, I_3 = \tfrac{1}{2}\right\rangle$$

M. Dugger (ASU), CLAS g8b run group, to be published

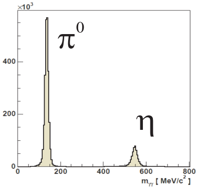
Beam Asymmetry Σ in $\vec{\gamma} p \to p\,\pi^0$ and $\vec{\gamma} p \to n\,\pi^+$



M. Dugger (ASU), CLAS g8b run group, to be published

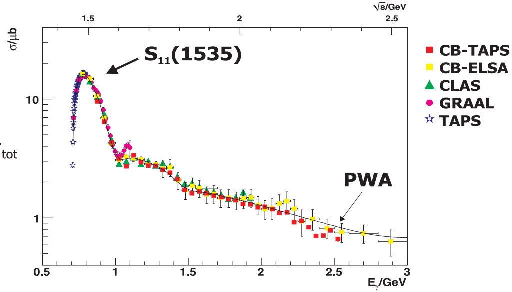
Why are Polarization Observables Important?

$\eta \longrightarrow \gamma\gamma$

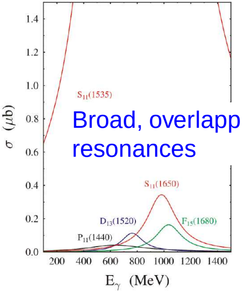


$d\sigma/d\Omega$

PWA



σ_{tot}

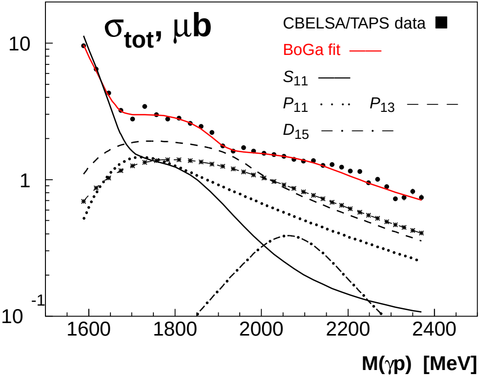


Broad, overlapping resonances

$\gamma p \longrightarrow p\eta$: Only nucleon (i.e. N^*) resonances can contribute

- $N(1535)S_{11}$, $N(1520)D_{13}$, $N(1650)S_{11}$, $N(1680)F_{15}$, $N(1720)P_{13}$, …, ρ- and ω-t-channel exchange
- New resonance $N(2070)D_{15}$: $m = (2068 \pm 22)$ MeV/c^2
  (Bonn-Gatchina PWA) $\Gamma = (295 \pm 40)$ MeV/c^2
  (needs confirmation in polarization experiments)

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



Resonances dominantly contributing:

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

Isospin Filter

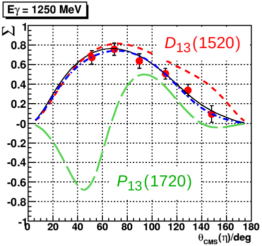
➜ Only N^* resonances can contribute!

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

(Phys. Rev. Lett. **94**, 012004 (2005))

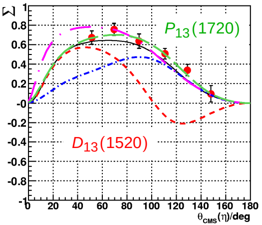
1. Confirmed in 2009 analysis!
2. $N(1720)P_{13} \to p\,\eta$?
   ➜ η-MAID: $N(1710)P_{11} \to p\,\eta$ significant!

Beam Asymmetry Σ in the Reaction $\vec{\gamma} p \to p\,\eta$



BoGa-PWA

$E_\gamma = 1250$ MeV



η-MAID

[CBELSA/TAPS Collaboration], EPJ A **33**, 147 (2007)

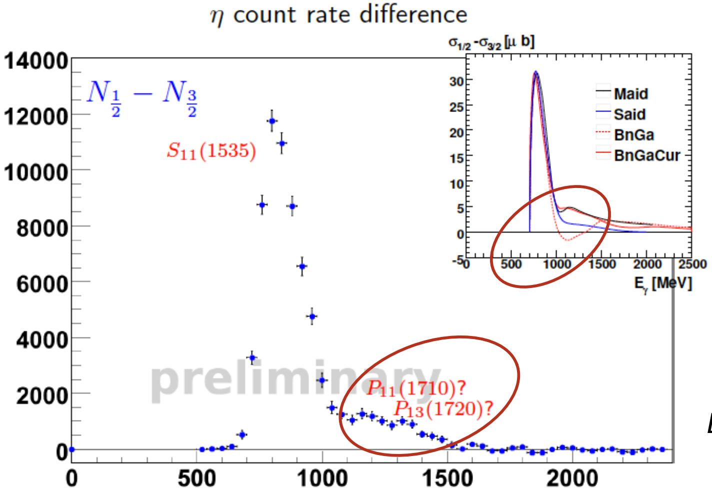
$$\frac{d\sigma}{d\Omega} = \sigma_0 \{ 1 - \delta_l \Sigma \cos 2\phi + \Lambda_x (-\delta_l \mathbf{H} \sin 2\phi + \delta_\odot \mathbf{F}) - \Lambda_y (-\mathbf{T} + \delta_l \mathbf{P} \cos 2\phi) - \Lambda_z (-\delta_l \mathbf{G} \sin 2\phi + \delta_\odot \mathbf{E}) \}$$

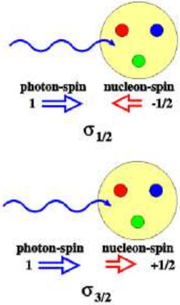
Further spin observables are available.

G and E from 2007-2009 experiments with longitudinal target polarization at MAMI-C, ELSA, CLAS ➜ Data being analyzed.

H, F, T, P from experiments with transverse target polarization (program completed at CLAS@JLab, soon at ELSA and MAMI)

Helicity-Dependent Cross Section for $\vec{\gamma}\vec{p} \rightarrow p\,\eta$

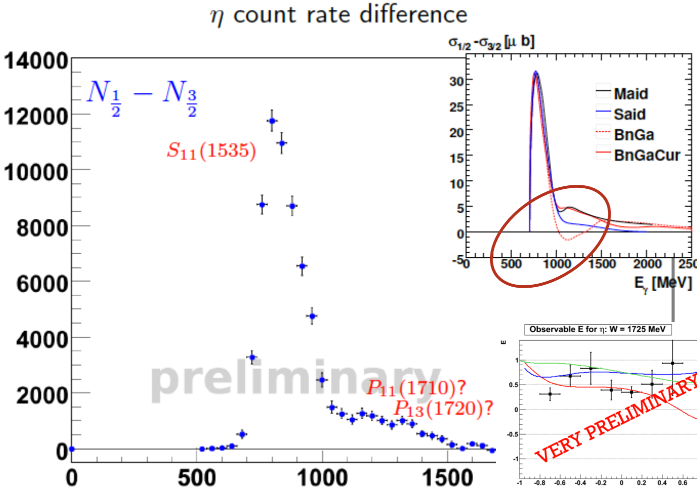




$$E = \frac{\sigma_{1/2} - \sigma_{3/2}}{\sigma_{1/2} + \sigma_{3/2}}$$

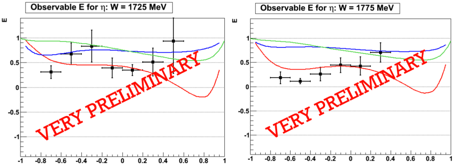
M. Gottschall *et al.* [CBELSA/TAPS Collaboration]

Helicity-Dependent Cross Section for $\vec{\gamma}\vec{p} \to p\,\eta$



M. Gottschall *et al.* [CBELSA/TAPS Collaboration]

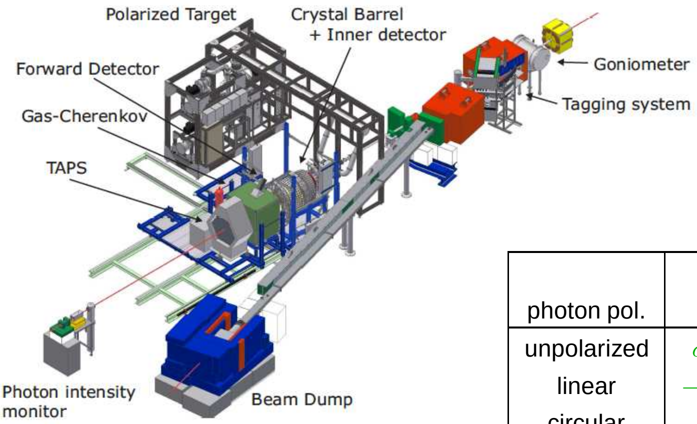
➜ Very preliminary: Data are positive

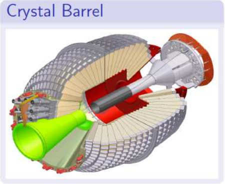


B. Morrison *et al.* [CLAS Collaboration]

Double-Polarization: Toward Complete Experiments

Calorimeter system at ELSA is optimized for neutral particles.



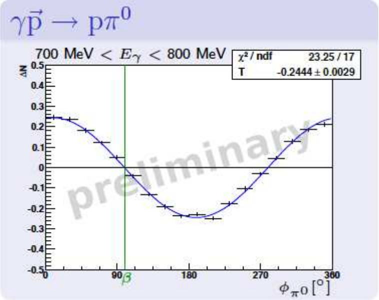


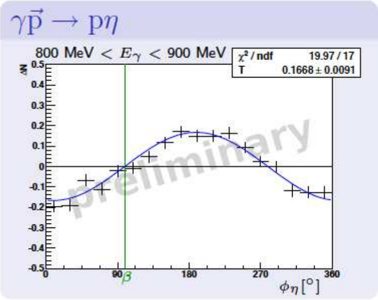
Close to 4π coverage

Frozen Spin Target: Butanol (C_4H_9OH).

		target pol. axis		
photon pol.		x	y	z
unpolarized	σ		T	
linear	$-\Sigma$	H	$-P$	$-G$
circular		F		$-E$

Double-Polarization at ELSA: Target Asymmetry T





D. Elsner
➜ Session 1C

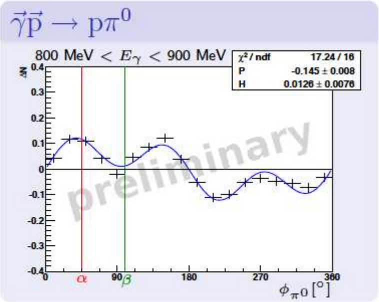
direction of target pol.: $\beta = 99°$

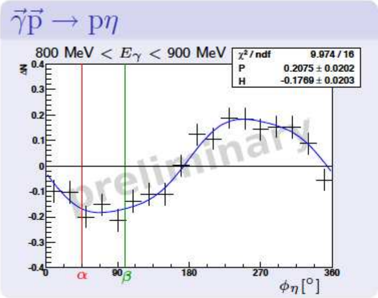
$$\Delta N(\phi) = \frac{1}{f\,P_{\text{target}}} \cdot \frac{N_\uparrow - N_\downarrow}{N_\uparrow + N_\downarrow} = T \cdot \sin(\phi - \beta)$$

➜ Unprecedented statistical quality.

photon pol.		target pol. axis x	target pol. axis y	target pol. axis z
unpolarized	σ		T	
linear	$-\Sigma$	H	$-P$	$-G$
circular		F		$-E$

Double-Polarization at ELSA: Observables P and H





angle of lin. pol. plane: $\alpha = 45°$

direction of target pol.: $\beta = 99°$

$$\Delta N(\phi) = C \cdot \frac{(N_{\perp\uparrow} - N_{\perp\downarrow}) - (N_{\parallel\uparrow} - N_{\parallel\downarrow})}{(N_{\perp\uparrow} + N_{\perp\downarrow}) + (N_{\parallel\uparrow} + N_{\parallel\downarrow})}$$

$$= P\,(\sin(\phi - \beta)\cos(2(\phi - \alpha)) + H\,(\cos(\phi - \beta)\sin(2(\phi - \alpha))$$

photon pol.		target pol. axis x	y	z
unpolarized	σ		T	
linear	$-\Sigma$	H	$-P$	$-G$
circular		F		$-E$

Double-Polarization at JLab: CLAS-FROST

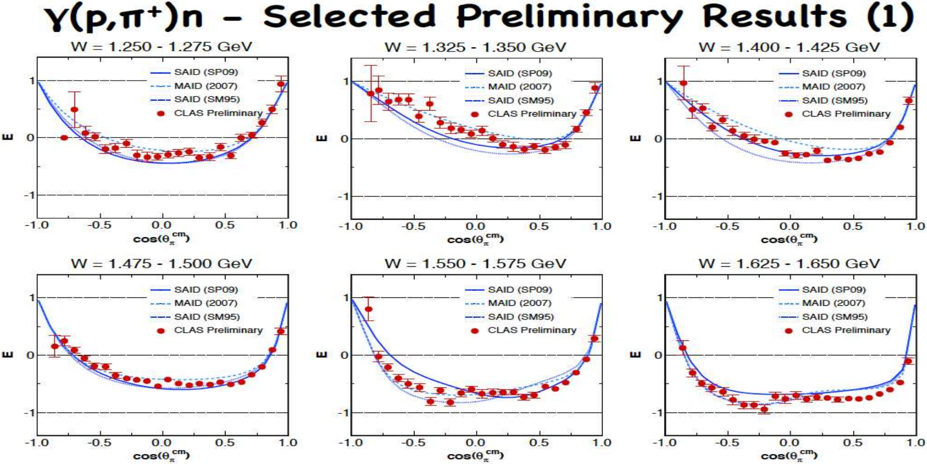
E. Pasyuk
➜ Session 1C

FRozen-Spin Target (FROST)

- $P_z \approx 80\,\%$
- Relaxation time $\sim$ 2,000 h
- Holding mode (B = 0.5 T, $T \approx$ 28 mK)

- $\gamma p \rightarrow p\,\eta$ (Dugger, Morrison *et al.*)
  Arizona State University
- $\gamma p \rightarrow p\,\omega$ (Collins, Vernarsky *et al.*)
  Catholic University, Carnegie Mellon
- $\gamma p \rightarrow n\,\pi^+$ (E) (S. Strauch *et al.*)
  University of South Carolina
- $\gamma p \rightarrow n\,\pi^+$ (G) (J. McAndrew *et al.*)
  University of Edinburgh
- $\gamma p \rightarrow p\,\pi^0$ (H. Iwamoto *et al.*)
  George Washington University
- $\gamma p \rightarrow p\,\pi^+\pi^-$ (S. Park *et al.*)
  Florida State University
- $\gamma p \rightarrow K^+ Y$ (S. Fegan *et al.*)
  University of Glasgow

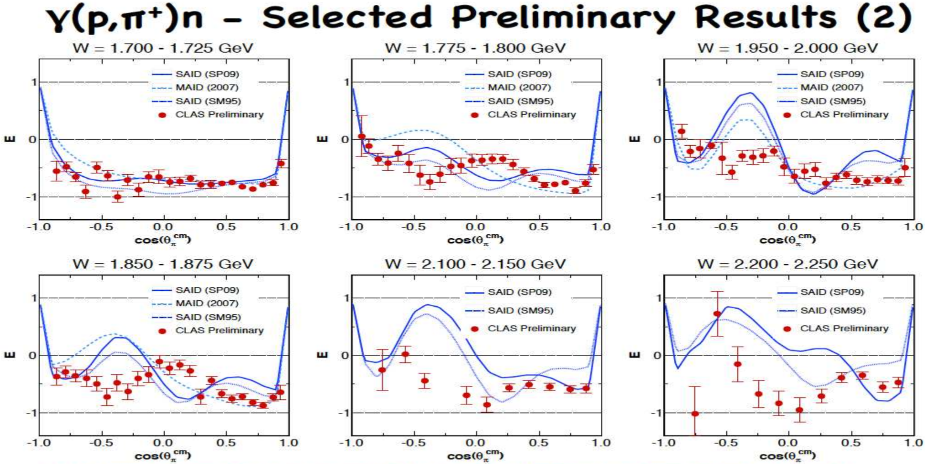
Helicity Difference E in $\gamma p \rightarrow n\pi^+$



SP09: M. Dugger, et al., Phys. Rev. C **79**, 065206 (2009); **SM95:** R. A. Arndt, I. I. Strakovsky, R. L. Workman, Phys. Rev. C **53**, 430 (1996); **MAID:** D. Drechsel, S.S. Kamalov, L. Tiator Nucl. Phys. **A645**, 145 (1999)

S. Strauch (University of South Carolina)

Helicity Difference E in $\gamma p \to n\pi^+$



SP09: M. Dugger, et al., Phys. Rev. C **79**, 065206 (2009); **SM95:** R. A. Arndt, I. I. Strakovsky, R. L. Workman, Phys. Rev. C **53**, 430 (1996);
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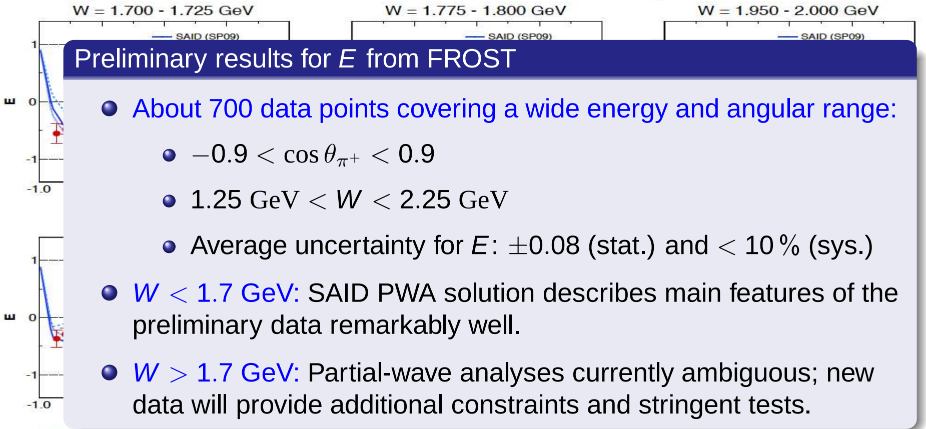
Helicity Difference E in $\gamma p \rightarrow n\,\pi^+$

$\gamma(p,\pi^+)n$ – Selected Preliminary Results (2)



Preliminary results for E from FROST

- About 700 data points covering a wide energy and angular range:
  - $-0.9 < \cos\theta_{\pi^+} < 0.9$
  - $1.25\ \mathrm{GeV} < W < 2.25\ \mathrm{GeV}$
  - Average uncertainty for E: ± 0.08 (stat.) and $< 10\,\%$ (sys.)
- $W < 1.7$ GeV: SAID PWA solution describes main features of the preliminary data remarkably well.
- $W > 1.7$ GeV: Partial-wave analyses currently ambiguous; new data will provide additional constraints and stringent tests.

SP09:
MAID: D. Drechsel, S.S. Kamalov, L. Tiator Nucl. Phys. A645, 145 (1999)

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Outline

1. Introduction
   - Quarks, QCD, and Confinement
   - Why do we study excited baryons?
2. The Search for Undiscovered States
   - Meson Photo-Production Data
   - Complete Experiments
3. Experimental Status of N^* (Polarization) Program
   - Polarization Experiments
   - Hadron Structure with Electromagnetic Probes
4. Summary and Outlook

	σ	Σ	T	P	E	F	G	H	T_x	T_z	L_x	L_z	O_x	O_z	C_x	C_z
Proton targets																
$p\pi^0$	✓ (red)	✓	✓ (blue)		✓	✓ (blue)	✓	✓ (blue)								
$n\pi^+$	✓ (red)	✓	✓ (blue)		✓	✓ (blue)	✓	✓ (blue)								
$p\eta$	✓ (red)	✓	✓ (blue)		✓	✓ (blue)	✓	✓ (blue)								
$p\eta'$	✓ (red)	✓	✓ (blue)		✓	✓ (blue)	✓	✓ (blue)								
$p\omega$	✓ (red)	✓	✓ (blue)		✓	✓ (blue)	✓	✓ (blue)								
$K^+\Lambda$	✓ (red)	✓	✓ (blue)	✓ (red)	✓	✓ (blue)	✓	✓ (blue)	✓ (blue)	✓ (blue)	✓	✓	✓	✓	✓ (red)	✓ (red)
$K^+\Sigma^0$	✓ (red)	✓	✓ (blue)	✓ (red)	✓	✓ (blue)	✓	✓ (blue)	✓ (blue)	✓ (blue)	✓	✓	✓	✓	✓ (red)	✓ (red)
$K^{0*}\Sigma^+$	✓ (red)	✓									✓	✓				
Neutron targets																
$p\pi^-$	✓ (red)	✓	✓ (green)		✓ (green)	✓ (green)	✓ (green)	✓ (green)								
$p\rho^-$	✓	✓	✓ (green)		✓ (green)	✓ (green)	✓ (green)	✓ (green)								
$K^-\Sigma^+$	✓	✓	✓ (green)		✓ (green)	✓ (green)	✓ (green)	✓ (green)								
$K^0\Lambda$	✓	✓	✓ (green)	✓	✓ (green)	✓ (green)	✓ (green)	✓ (green)	✓ (green)	✓ (green)	✓ (green)	✓ (green)	✓	✓	✓	✓
$K^0\Sigma^0$	✓	✓	✓ (green)	✓	✓ (green)	✓ (green)	✓ (green)	✓ (green)	✓ (green)	✓ (green)	✓ (green)	✓ (green)	✓	✓	✓	✓
$K^{0*}\Sigma^0$	✓	✓														

No recoil polarization for non-strange channels

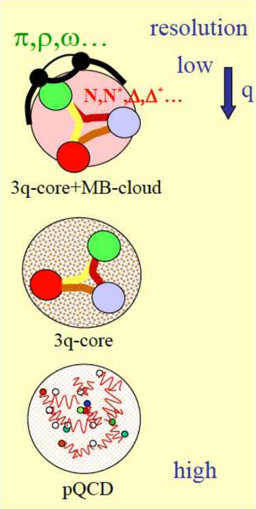
More observables for vector mesons: ω, ϕ, etc.

- ✓ (red) published
- ✓ acquired and being analyzed
- ✓ (blue) acquired at Jefferson Lab; being taken at ELSA, MAMI
- ✓ (green) planned

This is not boring stamp collection.

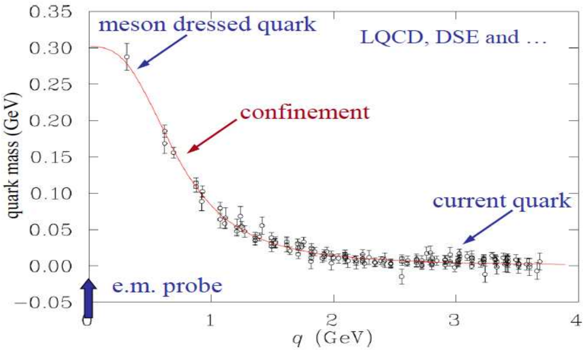
➜ We do not want to observe all resonances, but we need to find a pattern!

Hadron Structure with Electromagnetic Probes

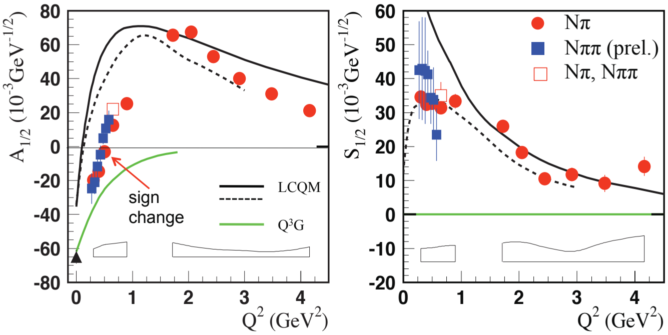


Study structure of the nucleon spectrum in domain where dressed quarks are the major active degree of freedom.

Explore formation of excited nucleon states in interactions of dressed quarks and their emergence from QCD.



Helicity Amplitudes for the “Roper” Resonance



Data from CLAS

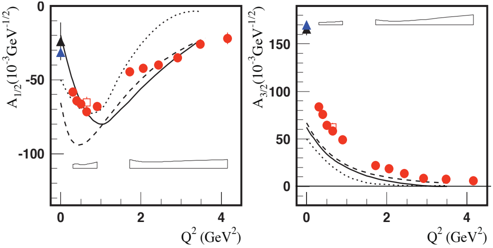
$A_{1/2}$ and $S_{1/2}$ amplitudes: e.g. I. Aznauryan *et al.*, PRC **78**, 045209 (2008)

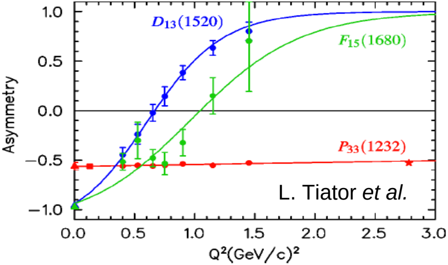
Consistency between both channels: sign change, magnitude, ...

- At short distances (high Q^2), Roper behaves like radial excitation.
- Low Q^2 behavior not well described by LF quark models: e.g. meson-baryon interactions missing

→ Gluonic excitation ruled out!

Helicity Amplitudes for $\gamma p \rightarrow N(1520)D_{13}$ Transition

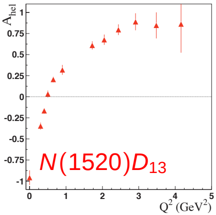




There is clear evidence for helicity switch from $\lambda = 3/2$ (at photon point) to $\lambda = 1/2$ at high Q^2:

- Rapid change in helicity structure when going from photo- to electroproduction of a nucleon resonance
  ➜ Stringent prediction of the CQM!

$$\mathcal{A}_{\text{hel}} = \frac{|A_{1/2}|^2 - |A_{3/2}|^2}{|A_{1/2}|^2 + |A_{3/2}|^2} \quad \rightarrow$$



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Summary and Outlook

The quest to understand confinement and the strong force is about to make great leaps forward:

- Progress in theory and computing will allow us to solve QCD and understand the baryon spectrum and the role of glue.
- New results from the current polarization programs worldwide will (soon) give us new insight on the observed and *missing* baryons.
  ➜ New candidates for baryon resonances have been proposed.
- The definitive experiments to confirm or refute current expectations on the role of glue are being built, e.g. GlueX@Jefferson Lab.

Conclusions

Advances in both areas will allow us to finally understand QCD and confinement.