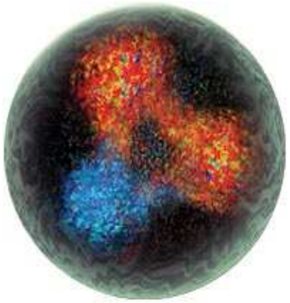
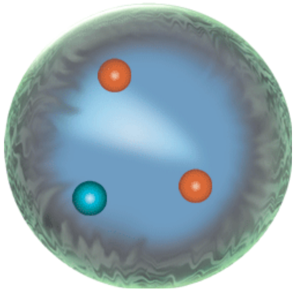
The N* Program at CLAS and CLAS12

Beach 2012 Tenth International Conference, on Hyperons, Charm, and Beauty Hadrons





Philip L Cole
Idaho State University

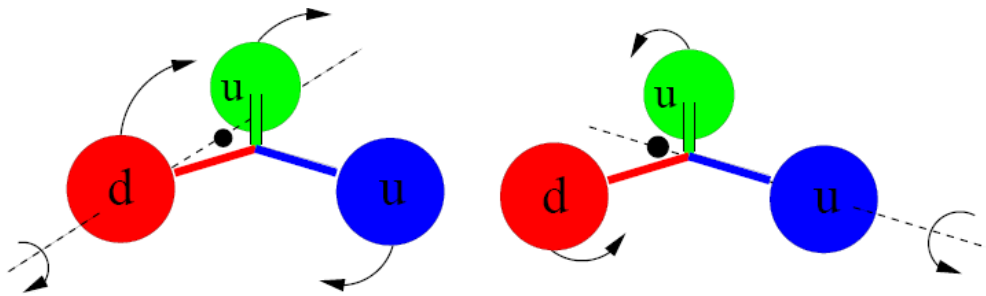
July 27, 2012

Jefferson Lab

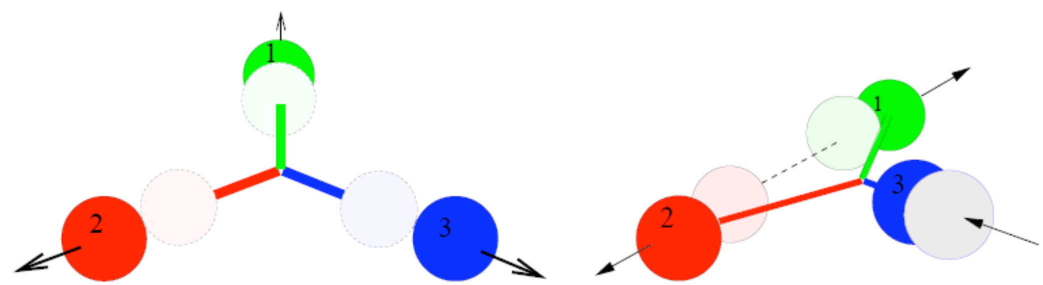
Wichita, Kansas

N and Δ Excited Baryon States …

- **Orbital excitations**
  (two distinct kinds in contrast to mesons)



- **Radial excitations**
  (also two kinds in contrast to mesons)



Message to take home

Why N*s are important (quoted from Nathan Isgur[1])

- *The first is that nucleons are the stuff of which our world is made.*
- *My second reason is that they are the simplest system in which the quintessentially nonabelian character of QCD is manifest.*
- *The third reason is that history has taught us that, while relatively simple, baryons are sufficiently complex to reveal physics hidden from us in the mesons.*

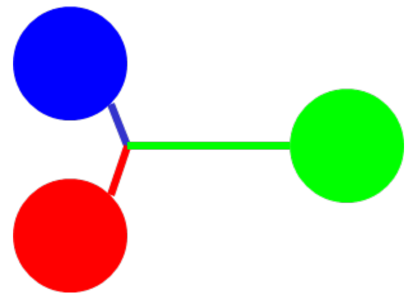
[1]Workshop on Excited Nucleons and Hadronic Structure (2000).

"Missing" Resonances?

Problem: symmetric CQM predicts many more states than observed (in πN scattering)

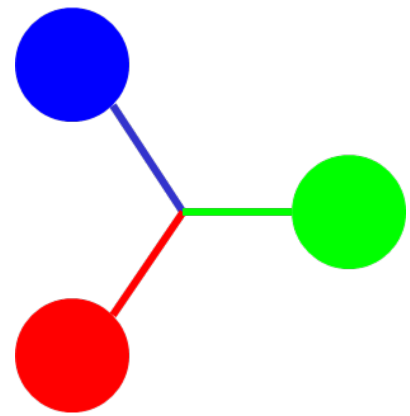
Possible solutions:

1. **diquark model**



- fewer degrees-of-freedom
- open question: mechanism for q^2 formation?

2. **not all states have been found**



- possible reason: decouple from πN-channel
- model calculations: missing states couple to $\pi\pi N$ ($\pi\Delta$, ρN), ωN, KY

γ coupling not suppressed → electromagnetic excitation is ideal

Baryon Resonances and SU(6) x O(3)

$|\text{Baryon}\rangle: \ \alpha\,|qqq\rangle + \beta\,|qqq(q\bar{q})| + \gamma\,|qqqG\rangle + ..$

3 Flavors: $\{u,d,s\} \longrightarrow SU(3)$

$\{qqq\}: \quad 3 \otimes 3 \otimes 3 = 10 \oplus 8 \oplus 8 \oplus 1$

Quark spin $s_q = ½ \longrightarrow SU(2)$

$\{\vec{q}\vec{q}\vec{q}\}: \quad 6 \otimes 6 \otimes 6 = 56 \oplus 70 \oplus 70 \oplus 20$

SU(6) multiplets decompose into flavor multiplets:

$56 = {}^4 10 \oplus {}^2 8$

$70 = {}^2 10 \oplus {}^4 8 \oplus {}^2 8 \oplus {}^2 1$

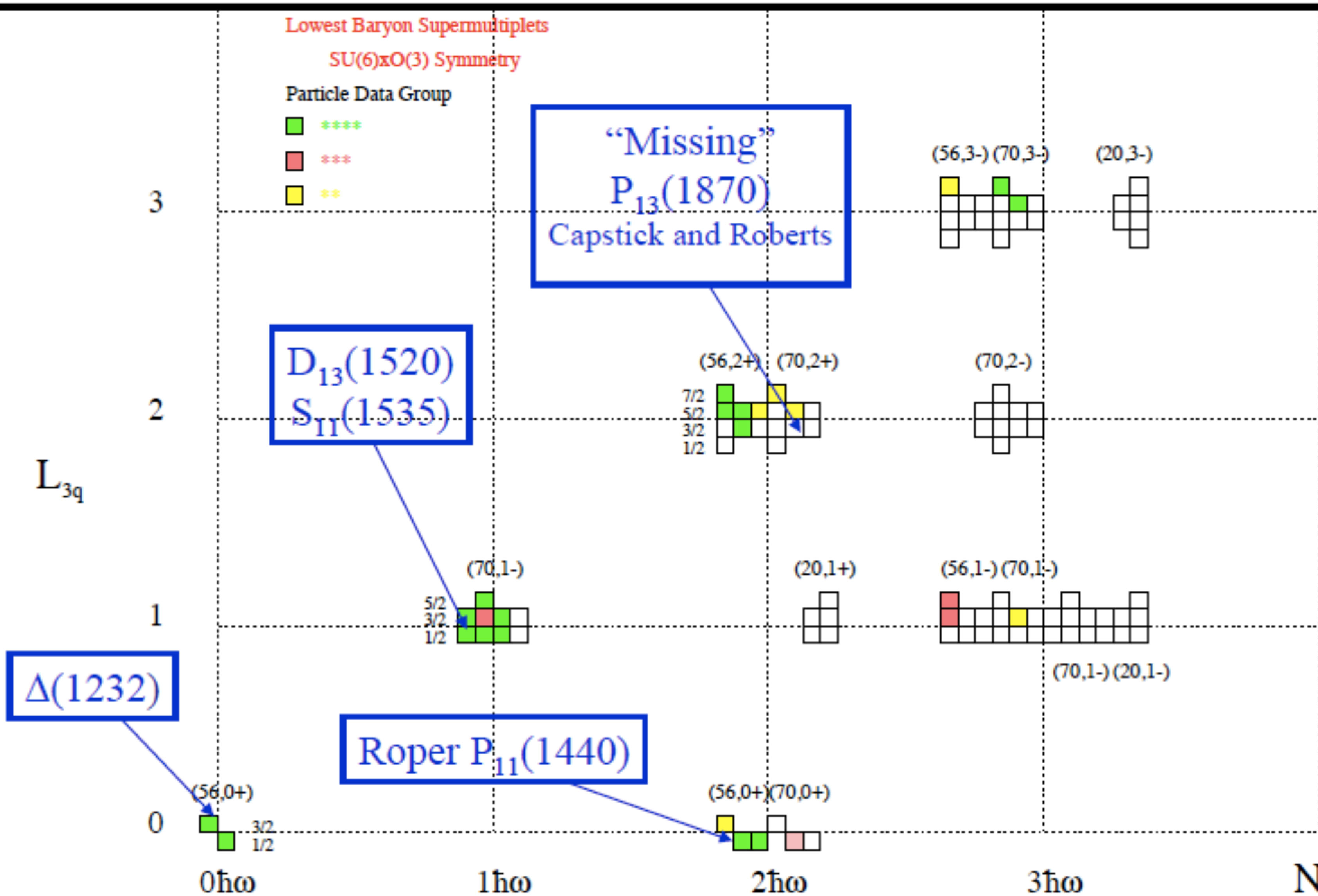
$20 = {}^2 8 \oplus {}^4 1$

O(3)

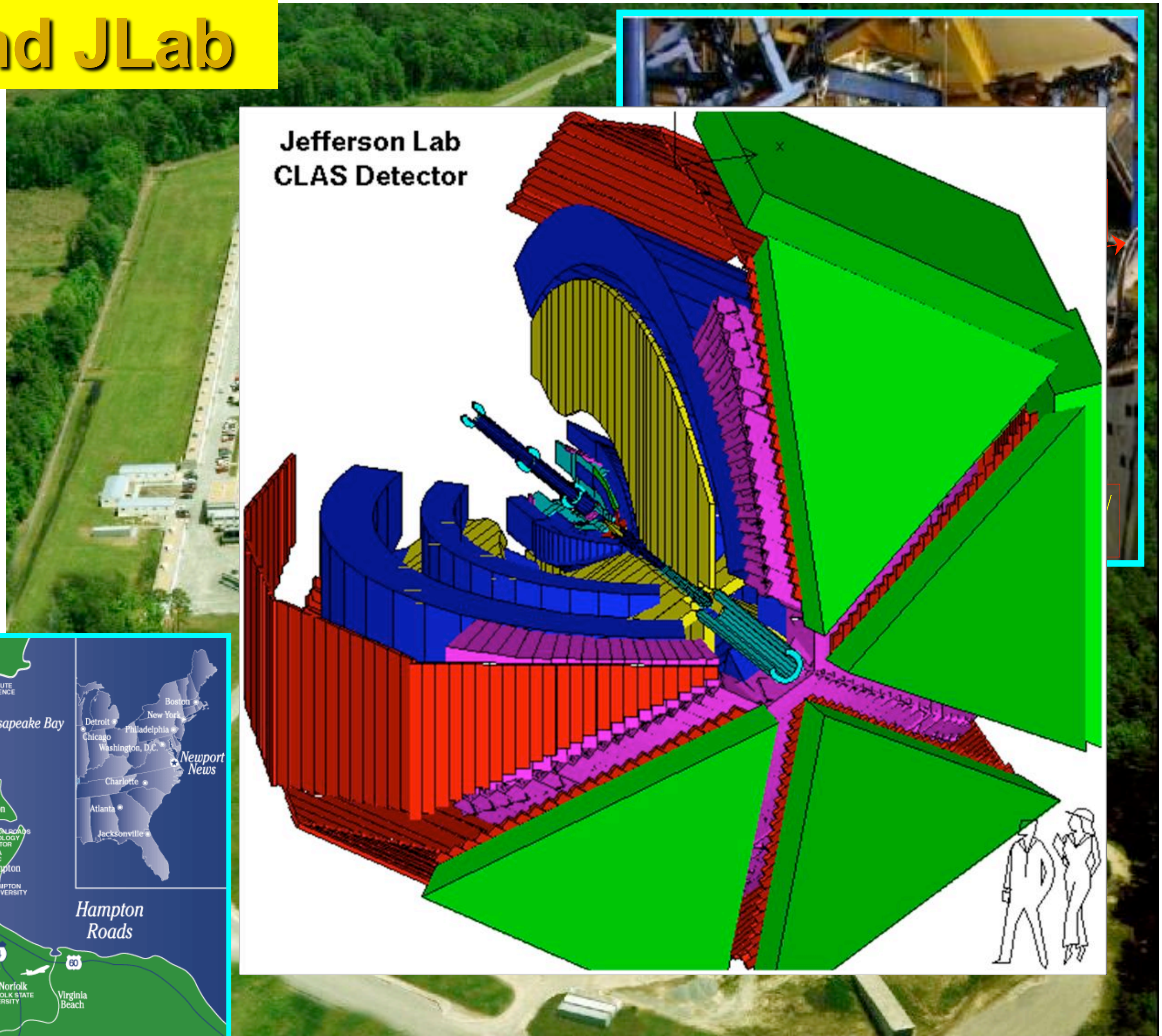
Baryon spin: $\vec{J} = \vec{L} + \Sigma \vec{s}_i$

parity: $P = (-1)^L$

SU(6) x O(3) Classification of Baryons



CLAS and JLab



Jefferson Lab

THOMAS JEFFERSON NATIONAL ACCELERATOR FACILITY

Electromagnetic Excitation of N*s

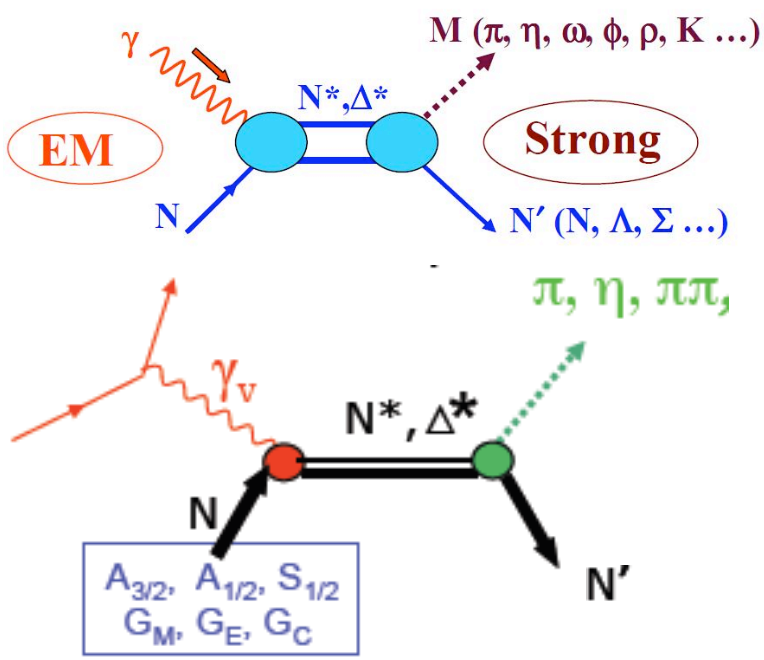
The experimental N* Program has two major components:

1) Transition helicity amplitudes of known resonances to study their internal structure and the interactions among constituents, which are responsible for resonance formation.

2) Spectroscopy of excited baryon states + search for new states.

- Both parts of the program are being pursued in various meson photo and electroproduction channels, e.g. $N\pi$, $p\eta$, $p\pi^+\pi^-$, $K\Lambda$, $K\Sigma$, $p\omega$, $p\rho^0$ using cross sections and polarization observables.
- Global analysis of ALL meson photo- and electroproduction channels – within the framework of an advanced coupled-channel approach – developed by EBAC (Excited Baryon Analysis Center – JLab) and to be continued by the Physics Analysis Center (JLab Theory Center and Argonne-Osaka collaboration).

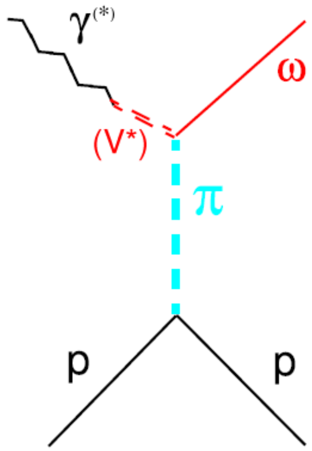
Photo & Electroproduction

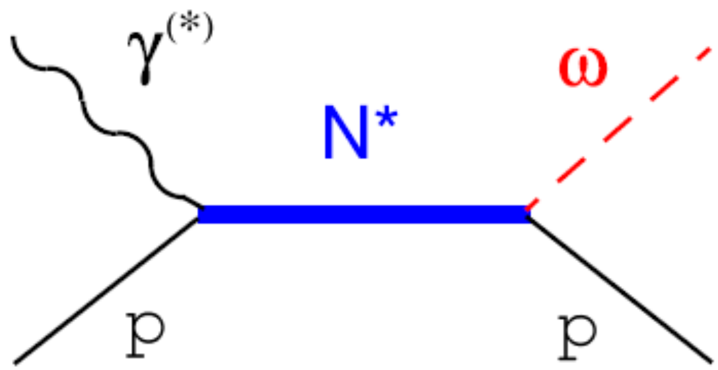


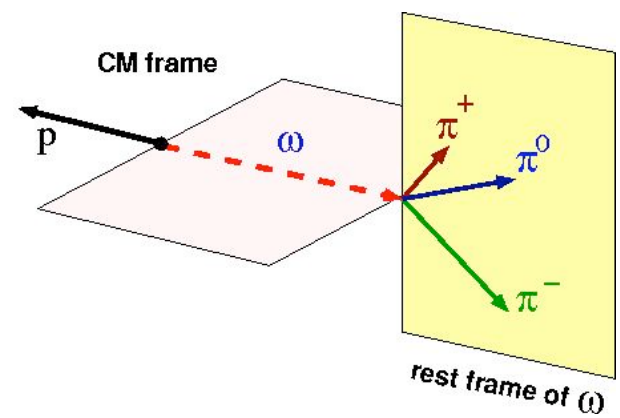
- Difficulties (New Opportunities)
  - Access to N* structure
  - Non-perturbative strong interactions responsible for formation of N*s
  - A lot of resonances could be present in a relatively narrow energy region
  - Nonresonance background is almost equally as complicated
- Experiments
  - Jefferson Lab (USA)
  - MAMI (Germany)
  - ELSA (Germany)
  - ESRF (France)
  - SPring-8 (Japan)
  - BES (China) ¶

¶ **A unique way of studying the baryon spectrum and N* hadronic decays is via BES: J/ψ → N*,…**

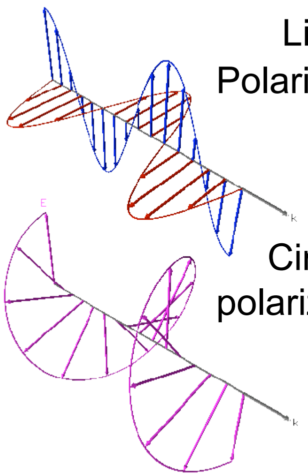
A few words on photoproduction







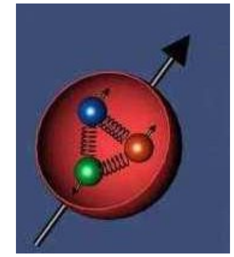
See Eugene Pasyuk's Talk (yesterday):
"Study of Hyperons with CLAS and CLAS12"



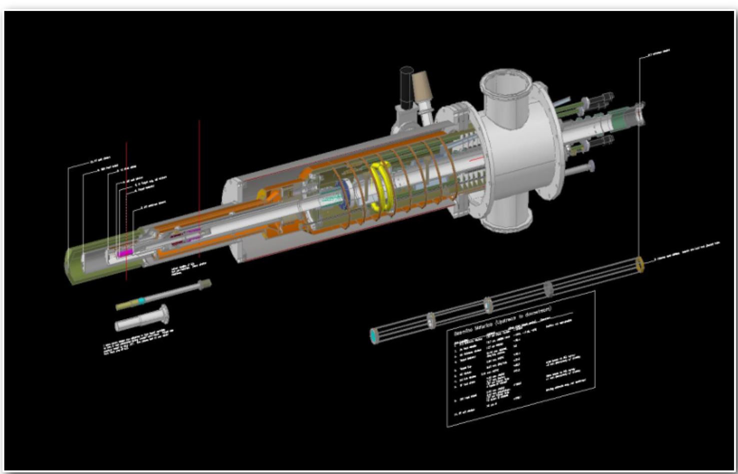
Linear Polarization ✓

Circular polarization ✓

$$\gamma + \mathbf{N} \rightarrow \mathbf{N} + \mathbf{m}$$
$$\rightarrow \mathbf{Y} + \mathbf{K}$$

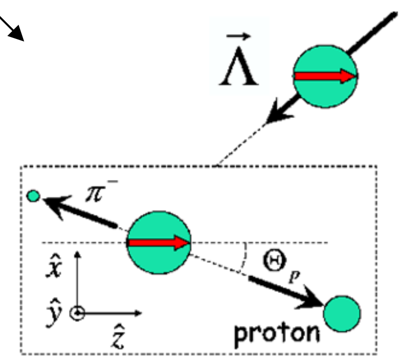


Nucleon recoil polarimeter x



Longitudinally polarized nucleon targets ✓

Transverse polarized nucleon targets ✓

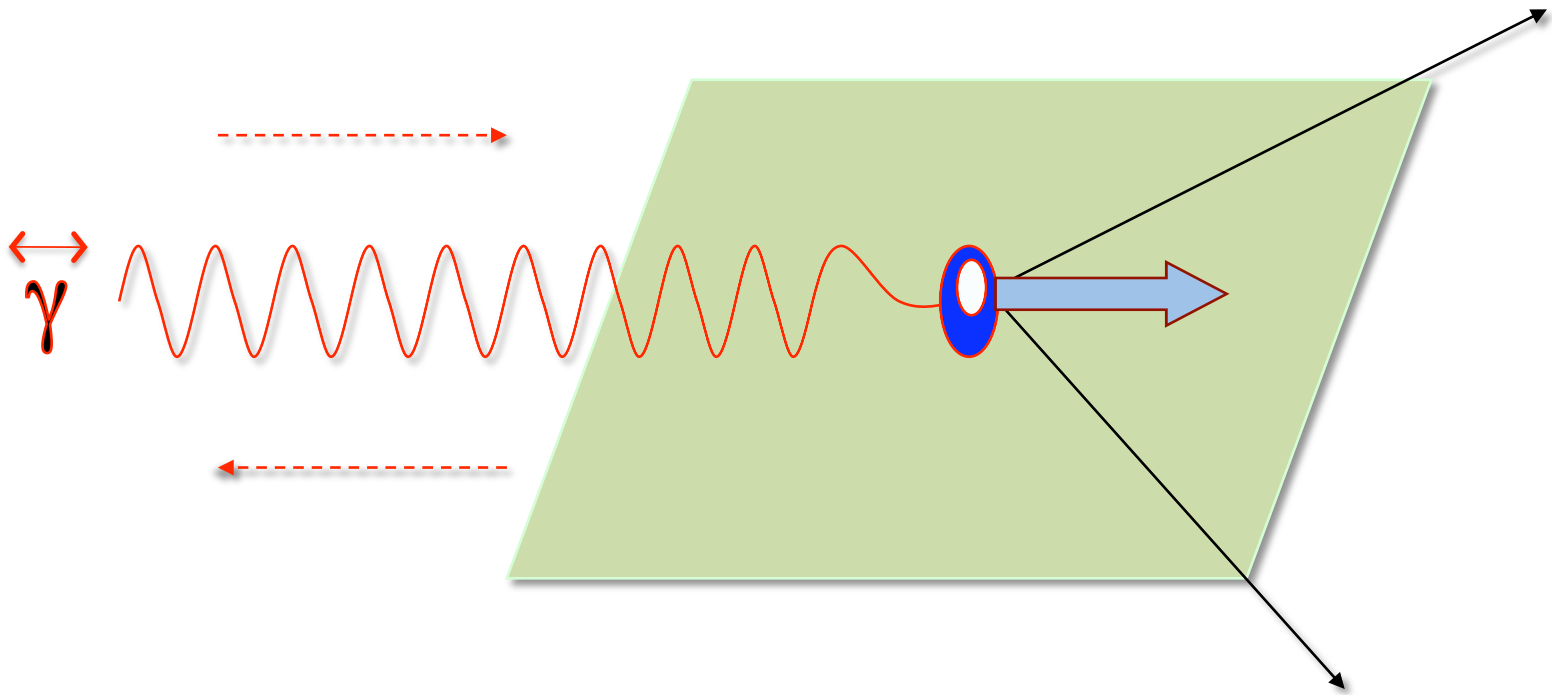


Hyperons are "self analyzing" ✓

Polarization Observables in K Photoproduction

- **Single-polarization observables**
  - Cross section (σ_0)
  - Recoil polarization (P)
  - Beam asymmetry (Σ)
  - Target asymmetry (T)
- **Double-polarization observables**
  - Beam + Recoil ($C_{x'}, C_{z'}, O_{x'}, O_{z'}$)
  - Beam + Target (E, F, G, H)
  - Recoil + Target ($T_{x'}, T_{z'}, L_{x'}, L_{z'}$)
- No observable requires triple polarization
- The first 8 can be measured without a polarized target
  - T is accessed as a double-polarization observable
- 16 observables in total - but they are not independent!

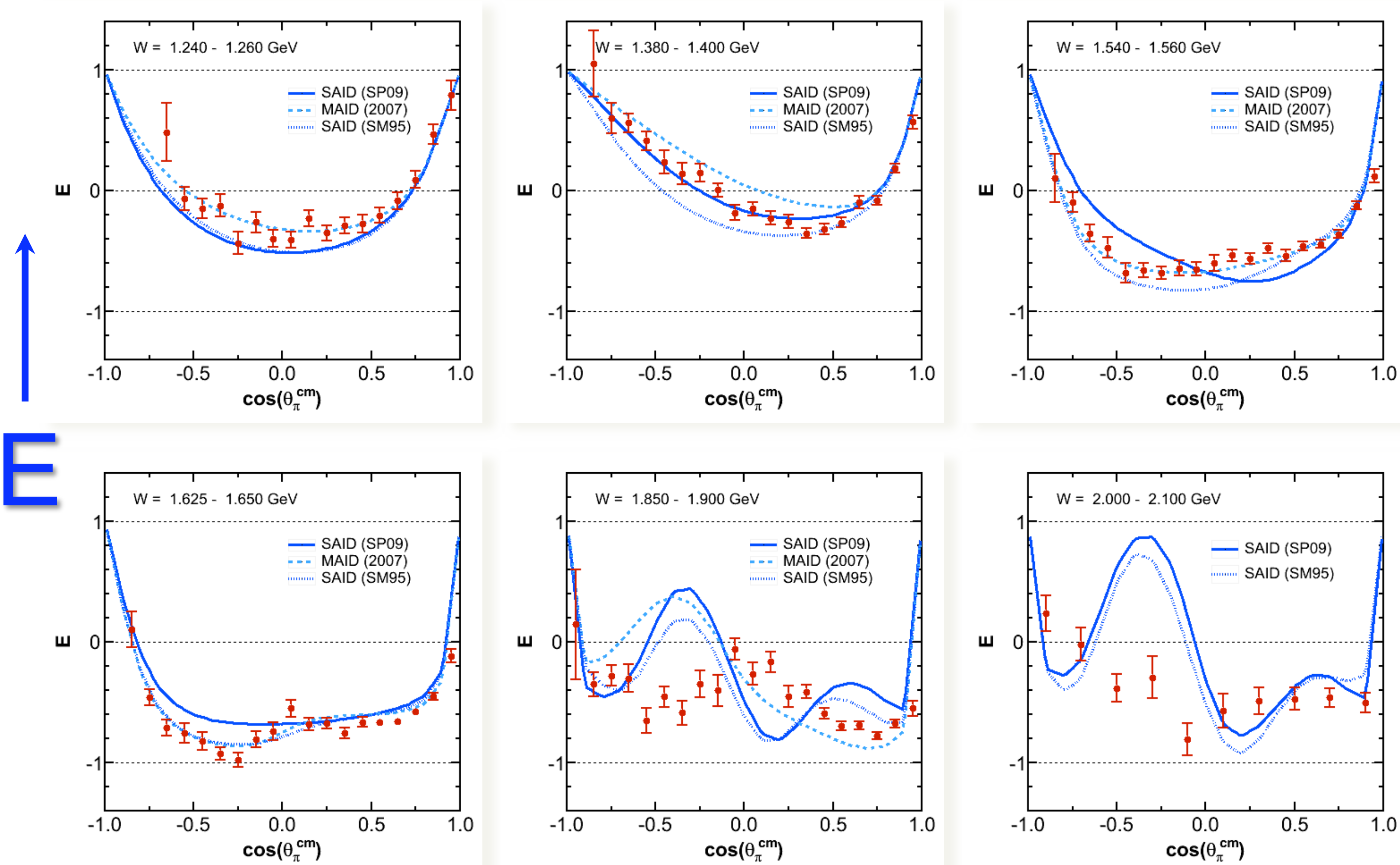
E Circularly polarized beam and longitudinally polarized target



$\vec{\gamma}(\vec{p},\pi^+)n$ - Selected Preliminary Results

Circular polarized beam and longitudinally polarized target

S. Strauch

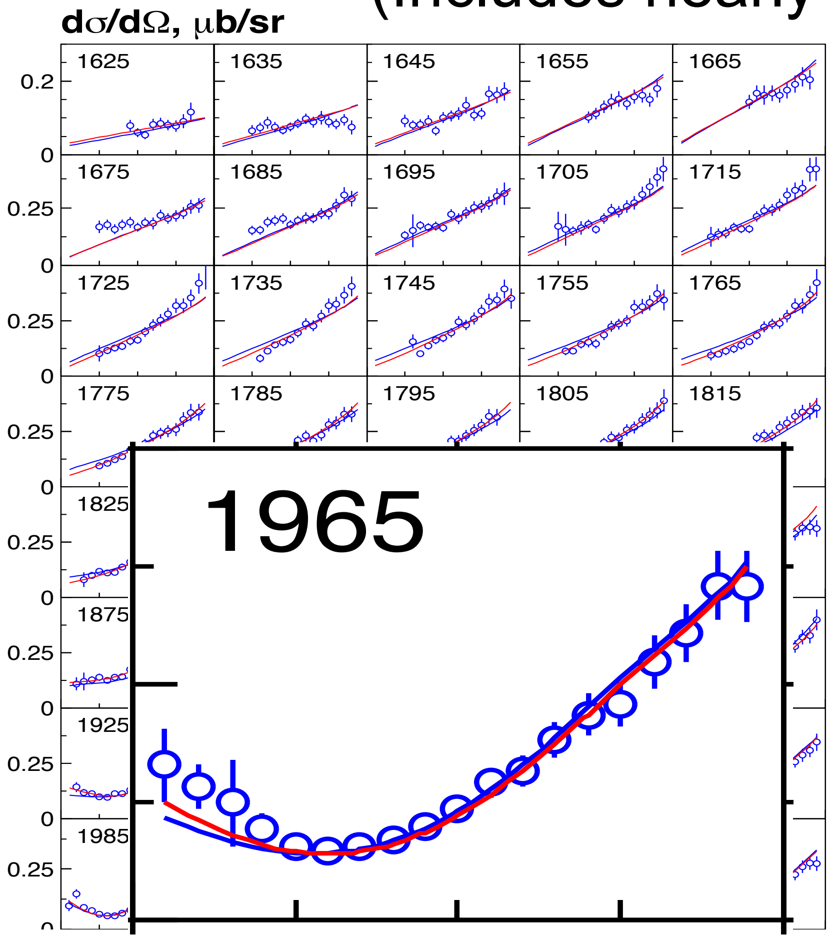


SP09: M. Dugger, et al., Phys. Rev. C 79, 065206 (2009); SM95: R. A. Arndt, I. I. Strakovsky, R. L. Workman, Phys. Rev. C 53, 430 (1996); MAID: D. Drechsel, S.S. Kamalov, L. Tiator Nucl. Phys. A645, 145 (1999)

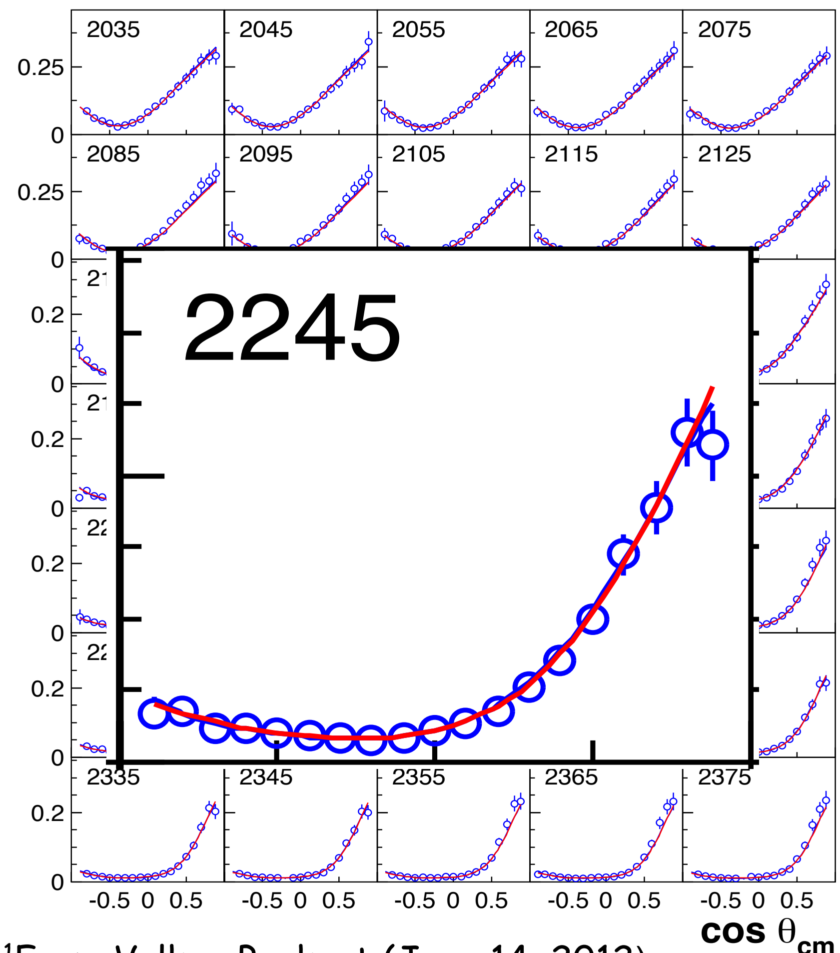
CLAS results[1] $\vec{\gamma}\vec{p} \rightarrow K^+\vec{\Lambda} \rightarrow K^+p\pi^-$

Bonn-Gatchina Coupled Channel Analysis, A.V. Anisovich *et al.*, EPJ A48, 15 (2012)

(Includes nearly all new photoproduction data)



M. Mc Cracken et al. (CLAS), Phys. Rev. C 81, 025201, 2010



[1]From Volker Burkert (June 14, 2012)

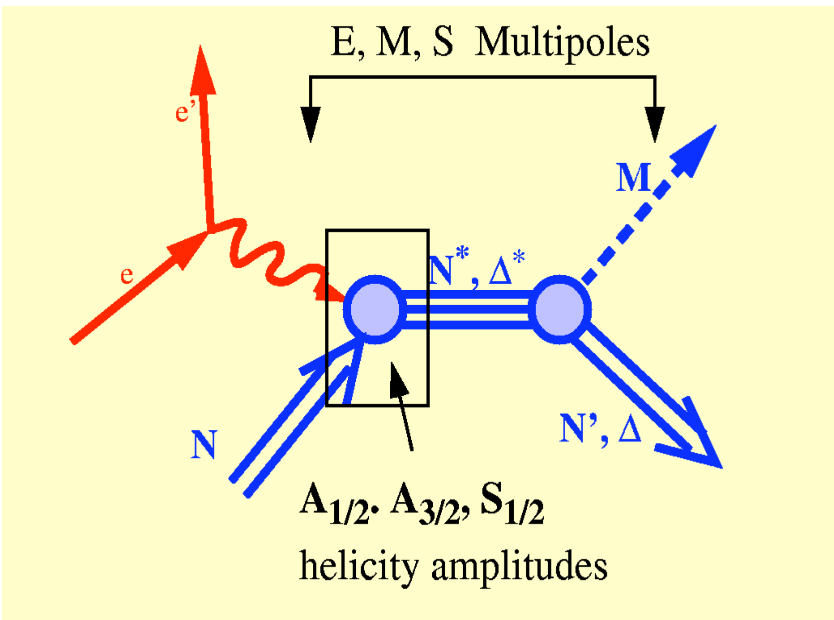
Evidence for new N* states and couplings[1]

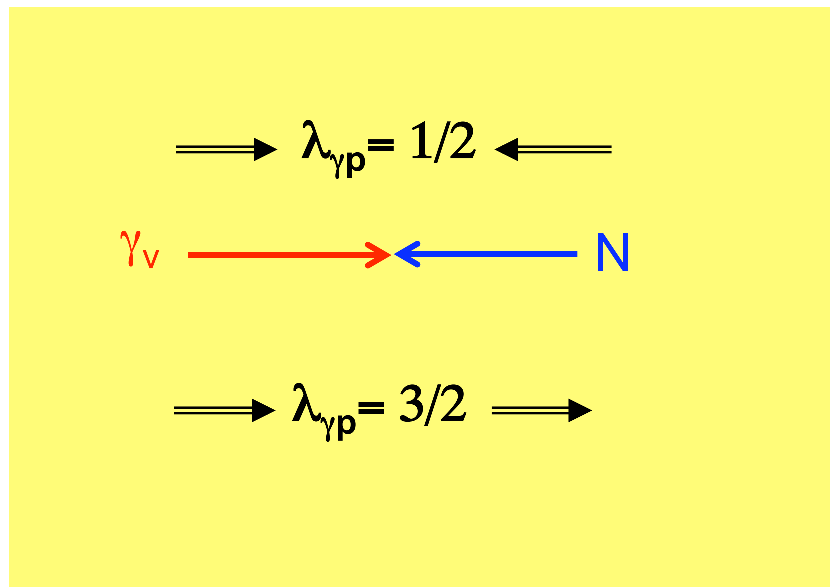
[1]From Volker Burkert (June 14, 2012)

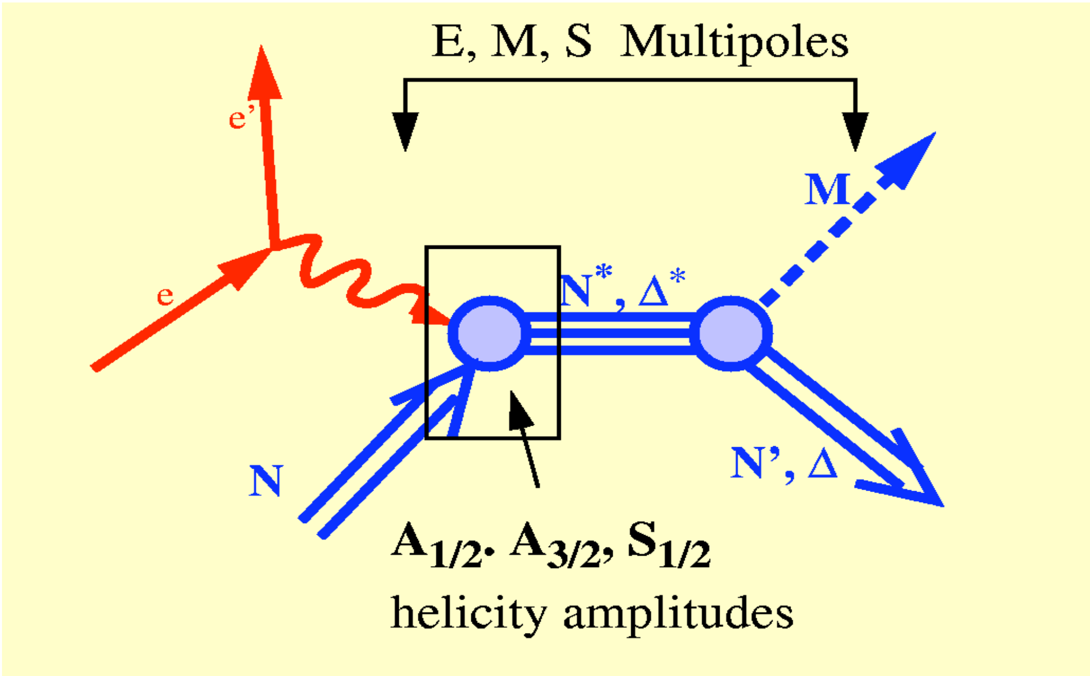
State N((mass)J^P	PDG 2010	PDG 2012	KΛ	KΣ	Nγ
$N(1710)1/2^+$	*** (not seen in GW analysis)	***	***	**	***
$N(1880)1/2^+$		**	**	*	**
$N(1895)1/2^-$		**	**	*	***
$N(1900)3/2^+$	**	***	***	**	***
$N(1875)3/2^-$		***	***	**	***
$N(2150)3/2^-$		**	**		**
$N(2000)5/2^+$	*	***	**	*	**
$N(2060)5/2^-$		***		**	***

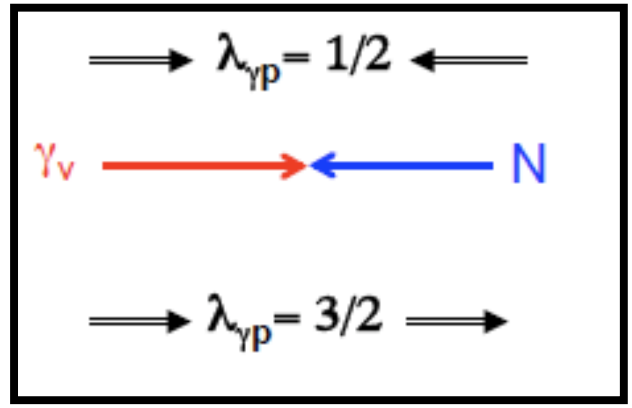
Bonn-Gatchina Analysis – A.V. Anisovich et al., EPJ A48, 15 (2012)
(First coupled-channel analysis that includes nearly all new photoproduction data)

Electron scattering and transition helicity amplitudes









The helicity amplitudes are related to the matrix elements of the electromagnetic current via:

$A_{1/2}$: $\langle N^*, S_z^* = +\frac{1}{2} | \varepsilon_\mu^{(+)} J^\mu_{em} | N, S_z = -\frac{1}{2} \rangle$

$A_{3/2}$: $\langle N^*, S_z^* = +3/2 | \varepsilon_\mu^{(+)} J^\mu_{em} | N, S_z = +\frac{1}{2} \rangle$

$S_{1/2}$: $\langle N^*, S_z^* = +\frac{1}{2} | \varepsilon_\mu^{(0)} J^\mu_{em} | N, S_z = +\frac{1}{2} \rangle$

Transverse
- $A_{1/2}$
- $A_{3/2}$

Longitudinal
- $S_{1/2}$

Studying N*s gives insight into structure

- **Active degrees of freedom in baryon structure at various distance scales.**

  The 6-GeV Program offers detailed information on the transition in N* structure from a superposition of meson-baryon and quark degrees of freedom to the quark-core dominance

- **Quark core regime**

  The quark core of the nucleon is especially important since N* properties are determined through interactions between dressed-quarks at distances larger than those most important to the structure of ground states.

- **γ_vNN* electrocouplings at the higher Q^2**

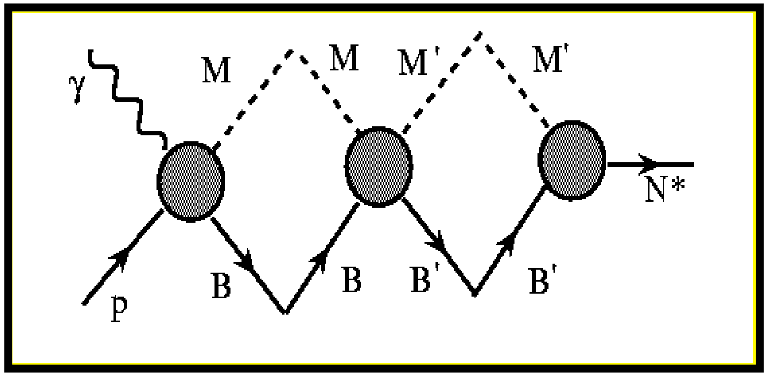
  Is dynamical chiral symmetry breaking in QCD the root cause for generating the vast bulk of the mass of observable matter in the universe?

Indeed in the words of the theorist, Craig Roberts:

"there is no greater challenge in the Standard Model, and few in physics, than learning to understand the truly non-perturbative long-range behavior of the strong interaction."

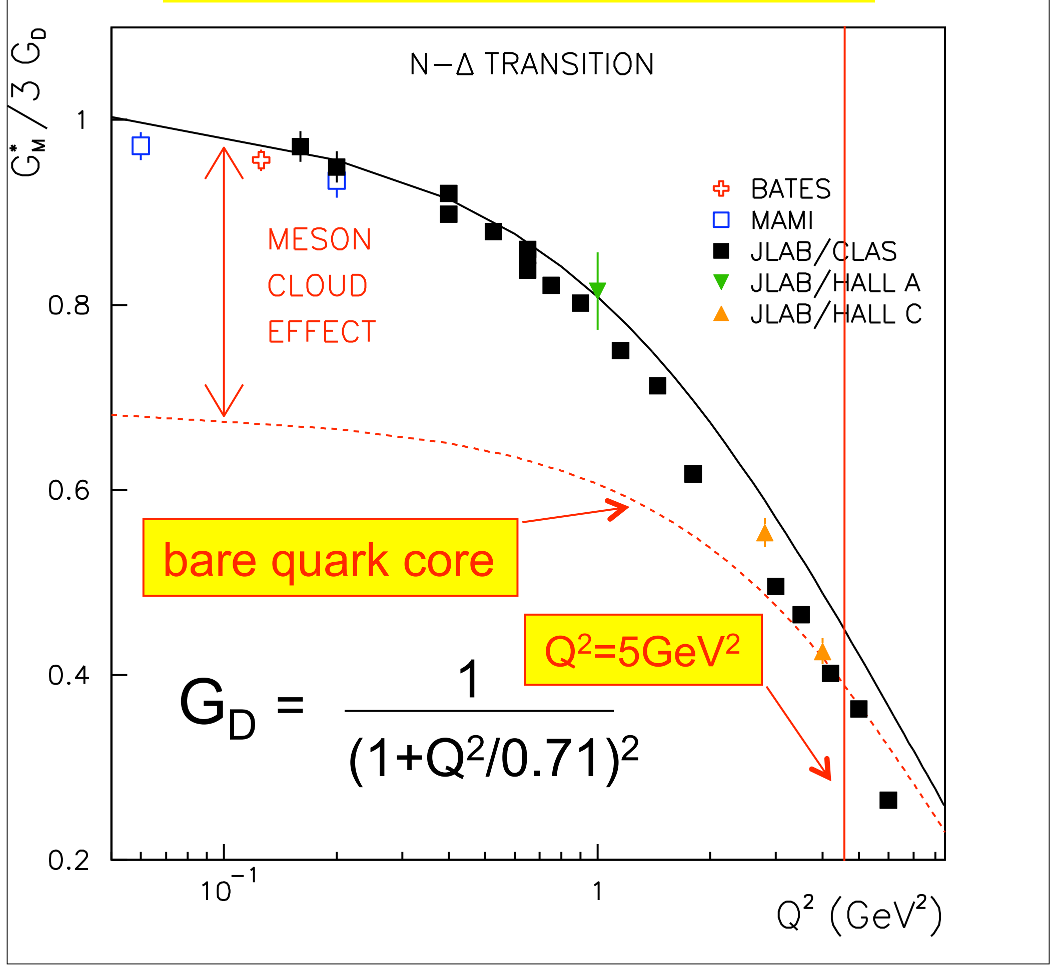
Effects of Meson-Baryon Dressing

One third of G^*_M at low Q^2 is due to contributions from meson-baryon (MB) dressing:



Within the relativistic Quark Model framework [B.Julia-Diaz *et al.*, PRC 69, 035212 (2004)], the bare-core contribution is reasonably described by the three-quark component of the wavefunction

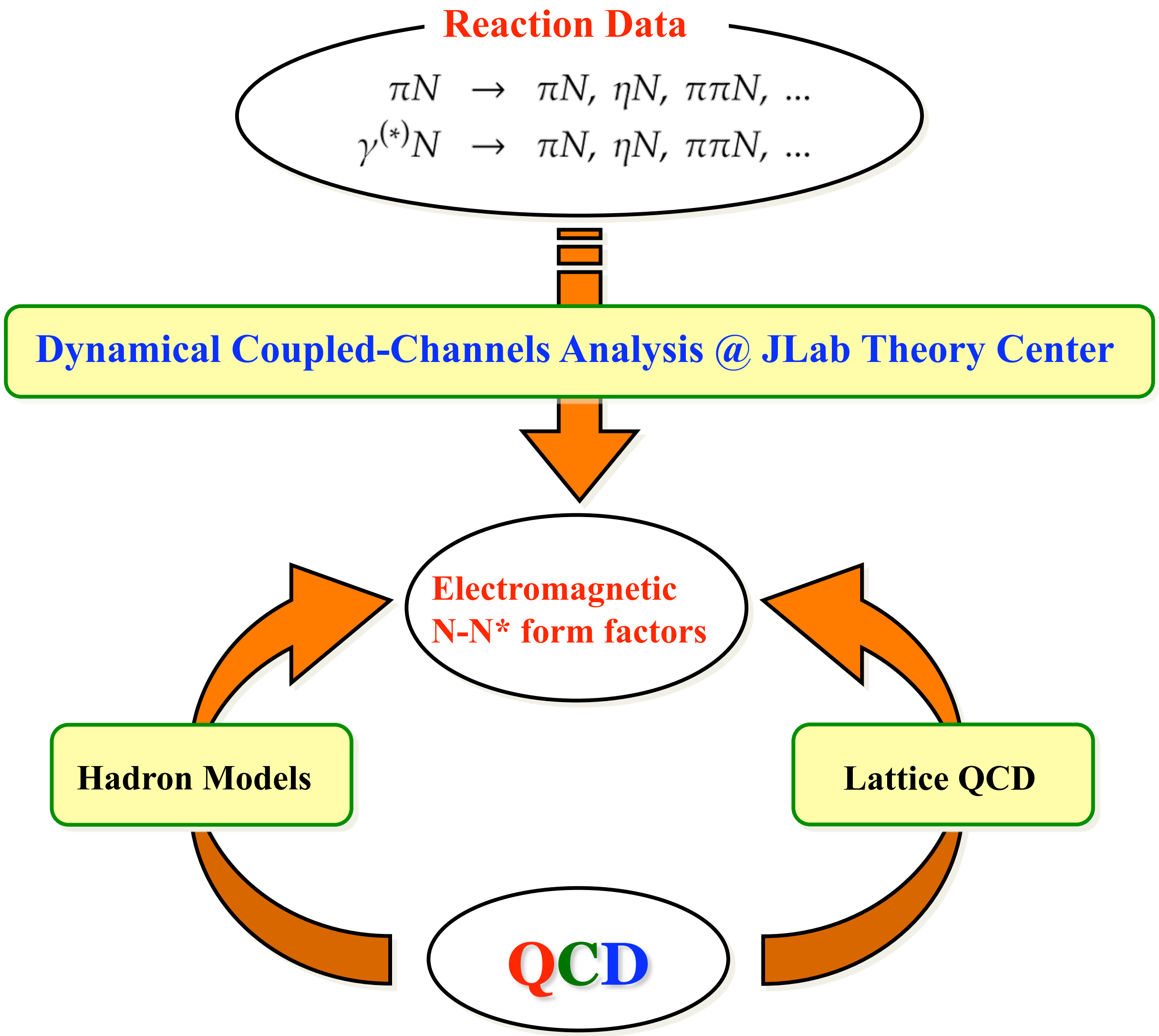
Data from exclusive π^0 production



Physics Goals for CLAS6

- Measure differential cross sections and polarization observables in single and double pseudo-scalar meson production: π^+n, π^0p, ηp, KY, and $\pi^+\pi^-p$ over the full polar and azimuthal angle range.
- Determine the transition form factors (i.e. electrocouplings) of prominent excited nucleon states (N^*, Δ^*) and their evolution in the range $Q^2 < 5$ GeV^2.
- Measure N* structure and its evolution with distance through the transition regime. Going from the "constituent quark region" of combined contributions of meson-baryon dressing and quark core at $Q^2 < 1.0$ GeV^2 to quark-core dominance at $Q^2 > 5.0$ GeV^2.

EBAC strategy (summary)

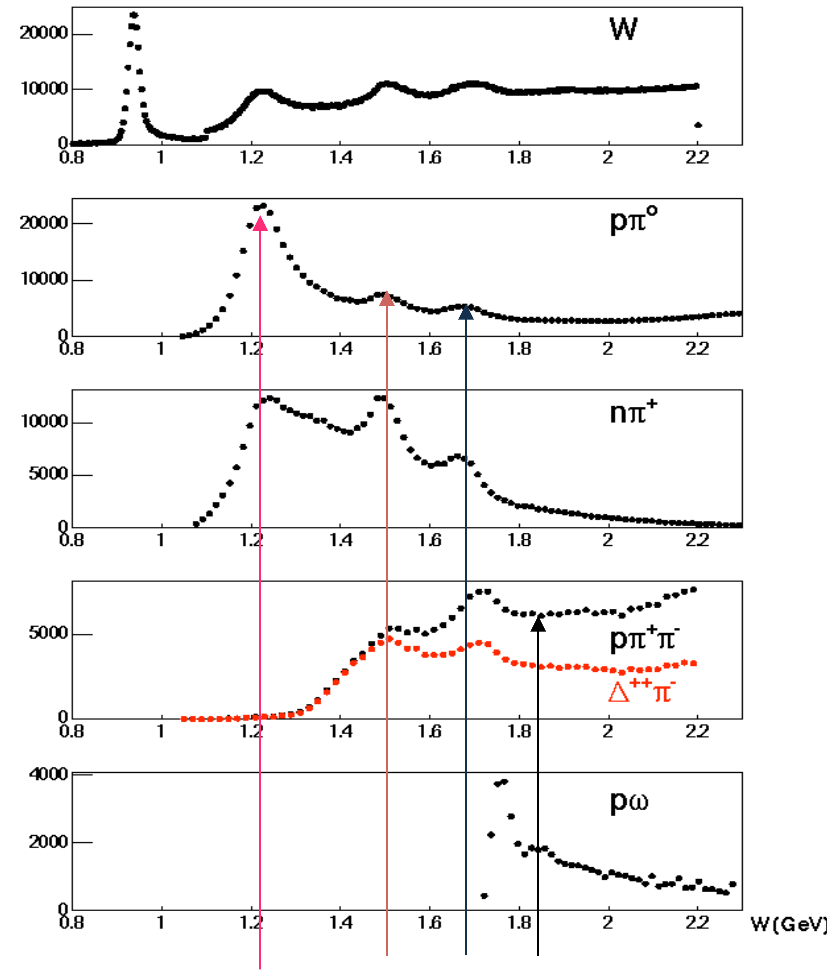


Why $N\pi/N\pi\pi$ electroproduction channels are important

- **$N\pi/N\pi\pi$ channels are the two major contributors in N* excitation region;**
- **these two channels combined are sensitive to almost all excited proton states;**
- **they are strongly coupled by $\pi N \rightarrow \pi\pi N$ final state interaction;**
- **may substantially affect exclusive channels having smaller cross sections, such as ηp, $K\Lambda$, and $K\Sigma$.**

Therefore knowledge on $N\pi/N\pi\pi$ electroproduction mechanisms is key for the entire N* Program

CLAS data on meson electro-production at $Q^2 < 4.0$ GeV^2



Summary of the CLAS data on single-pion electroproduction off protons

Number of data points >116000, W<1.7 GeV, $0.15<Q^2<6.0$ GeV^2 , almost complete coverage of the final state phase space.

Observables	Q^2 Range [GeV^2]	Number of data points
$d\sigma/d\Omega(\pi^0)$	0.16-1.45 3.0-6.0	39830 9000
$d\sigma/d\Omega(\pi^+)$	0.25-0.60 1.7-4.3	25588 30 849
$A_e(\pi^0)$, $A_t(\pi^0)$	0.25-0.65	3981
$A_e(\pi^+)$, $A_t(\pi^+)$	0.40-065 1.7 - 3.5	1730 3 535
$A_{et}(\pi^0)$	0.25-0.61	1521

Low Q^2 results:
I. Aznauryan *et al.*,
PRC 71, 015201 (2005);
PRC 72, 045201 (2005).

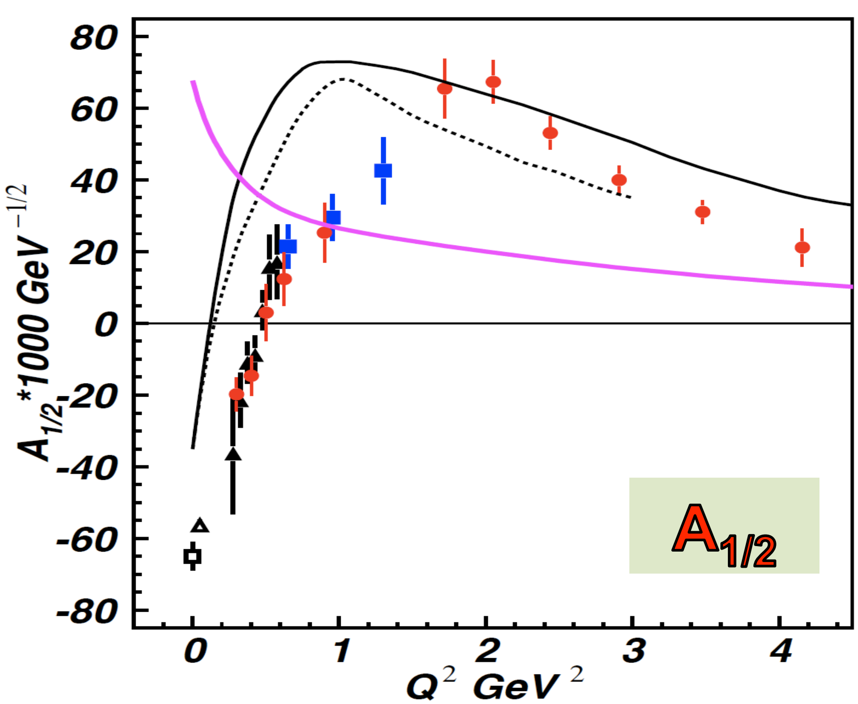
High Q^2 results on Roper:
I. Aznauryan *et al.*,
PRC 78, 045209 (2008).

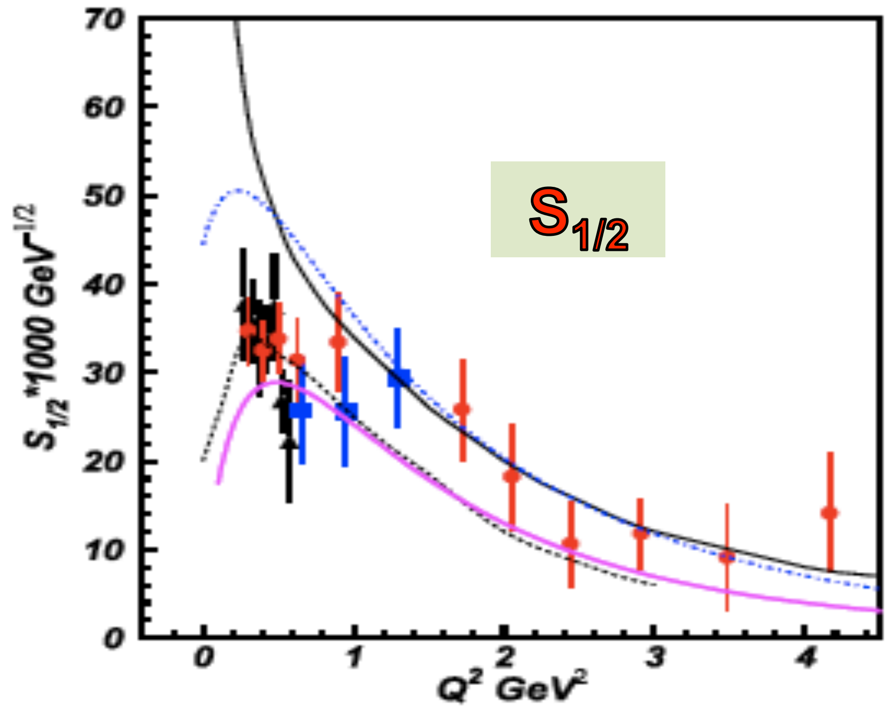
Final analysis:

I.G.Aznauryan, V.I Mokeev, V.D. Burkert (CLAS Collaboration), PRC 80. 055203 (2009).

All datasets can be found in: http://clasweb.jlab.org/physicsdb/

The $P_{11}(1440)$ electrocouplings from the CLAS data



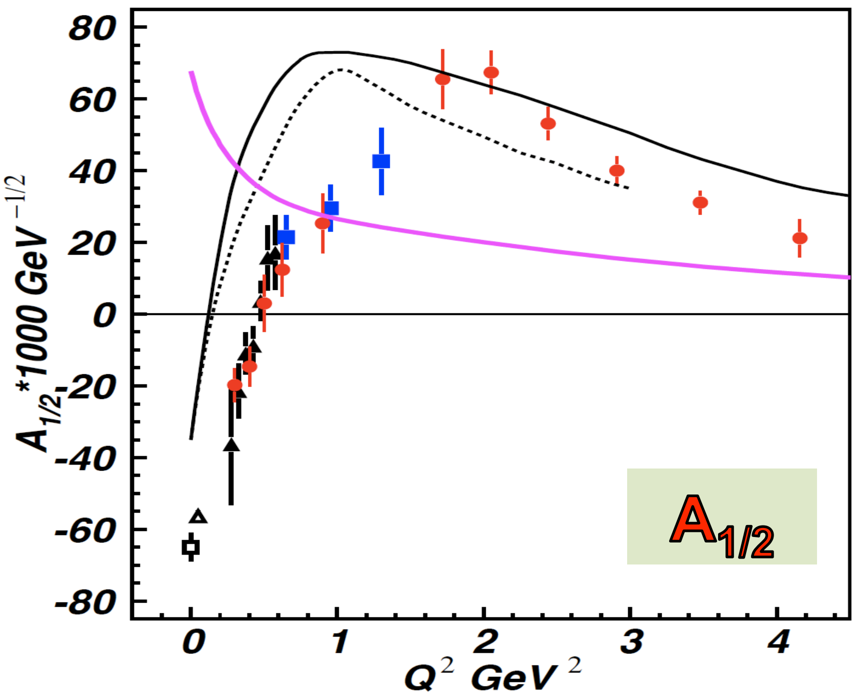


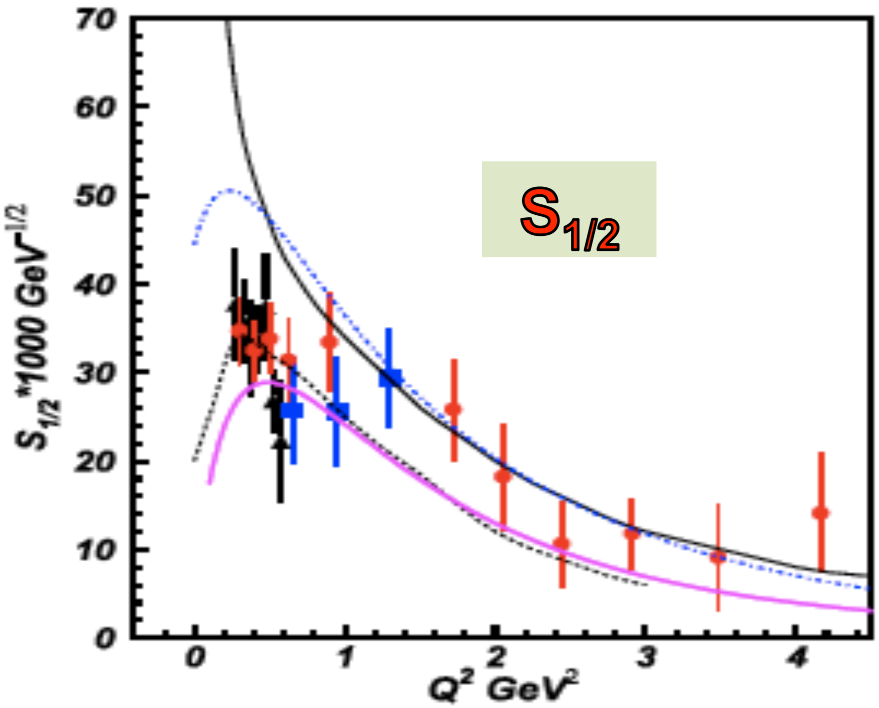
▲ $\pi^+\pi^-p$ (2010) ■ $\pi^+\pi^-p$ (2012) ● πN

Quark models

- ——— I. Aznauryan *et al.*, PRC 76, 025212 (2007) Light Cone
- - - - - S. Capstick and B.D. Keister, PRD 51, 3398 (1995) Light Cone
- -·-·-· G.Ramalho and K. Tsushima, PRD 81, 074020 (2010) Relativistic Covariant
- ——— Meson-Baryon Dressing absolute value (EBAC) B. Julia-Diaz et al. PRC 77 045205, (2008)

The $P_{11}(1440)$ electrocouplings from the CLAS data

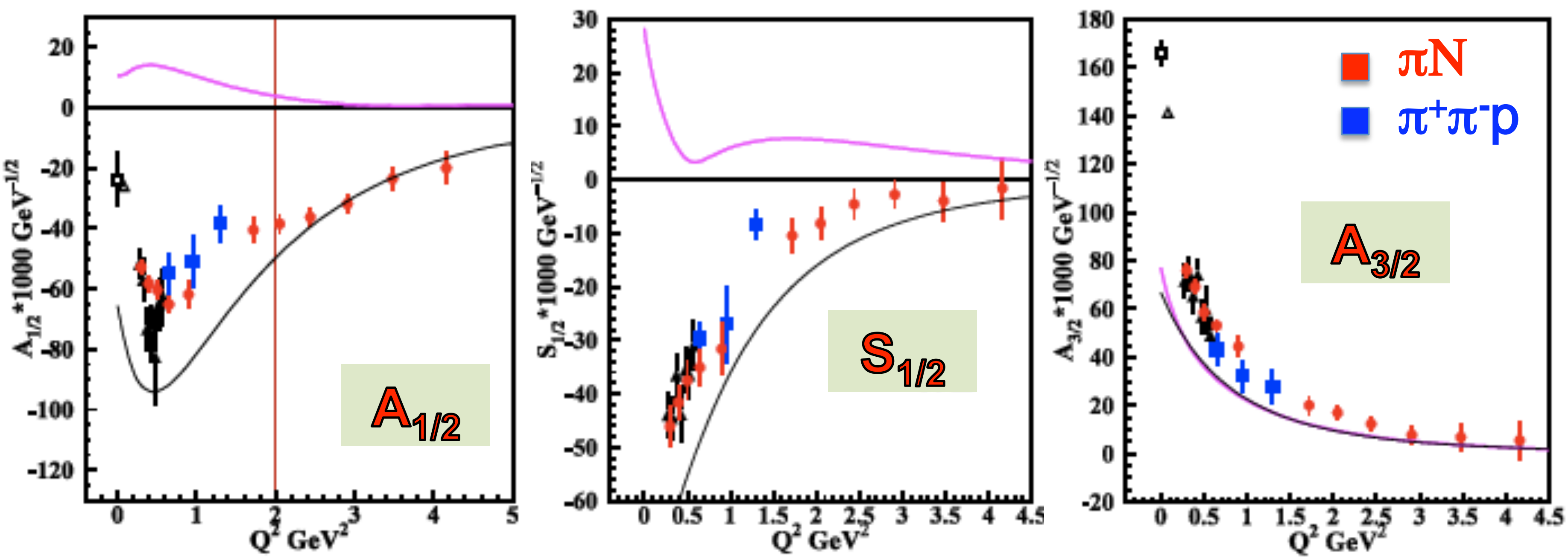




- **Consistent values of $P_{11}(1440)$ electrocouplings determined in independent analyses of Nπ and $\pi^+\pi^-$p exclusive channels strongly support reliable electrocoupling extraction.**

- **The physics analyses of these results revealed the *$P_{11}(1440)$* structure as a combined contribution of: a) quark core as a first *radial excitation of the nucleon as a 3-quark ground state, and b) meson-baryon dressing*.**

The $D_{13}(1520)$ electrocouplings from the CLAS data



hybrid Constituent Quark Model (hQCM)
M.Aiello, M.M. Giannini, and E.Santopinto, J. Phys G **24**, 753 (1998)

Meson-Baryon Dressing absolute value (EBAC)

- at Q^2>2.0 GeV^2 electrocouplings are consistent with $D_{13}(1520)$ structure as three dressed quarks in orbital excitation with L=1.
- sizable meson-baryon cloud at Q^2<1.0 GeV^2.

Announcement of Firsts from CLAS

- First electroproduction data:
  - channels: π^+n, π^0p, and ηp
  - Q^2 evolution information on the $\gamma_v NN^*$ electrocouplings for the states: $P_{33}(1232)$, $P_{11}(1440)$, $D_{13}(1520)$, and $S_{11}(1535)$ for $Q^2 < 5.0$ GeV.

I.G. Aznauryan *et al.*, (CLAS Collaboration) Phys. Rev. **C80,** 055203 (2009).

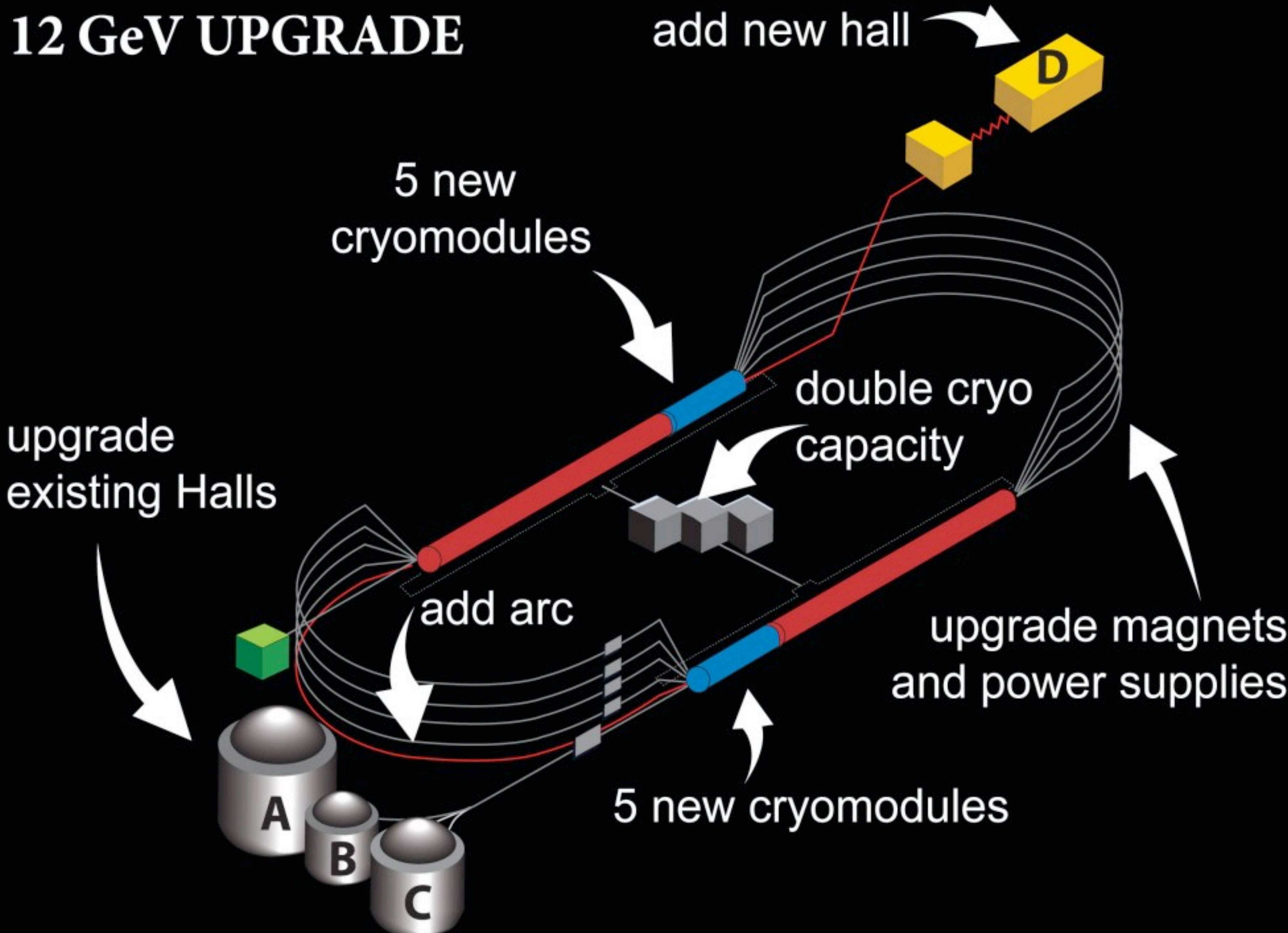
- We recently published the preliminary (first) results on the electrocouplings of the states $P_{11}(1440)$, $D_{13}(1520)$, $S_{31}(1620)$, $D_{33}(1700)$, and $P_{13}(1720)$ at $0.5 < Q^2 < 1.5$ GeV^2 in $N\pi\pi$ electroproduction from protons

V.I. Mokeev, I.G. Aznauryan, V.D. Burkert, arXiv:1109.1294 [nucl-ex] **+**
I.G. Aznauryan, V.D. Burkert, V.I. Mokeev, arXiv:1108.1125 [nucl-ex]

See our latest N* paper and the references therein:

V. Mokeev *et al.* (CLAS Collaboration), "A Study of the $P_{11}(1440)$ and $D_{13}(1520)$ Resonances from CLAS Data on $ep \rightarrow e'\pi^+\pi^-p'$," arXiv:1205.3948, accepted by Phys. Rev. C (2012).

12 GeV UPGRADE



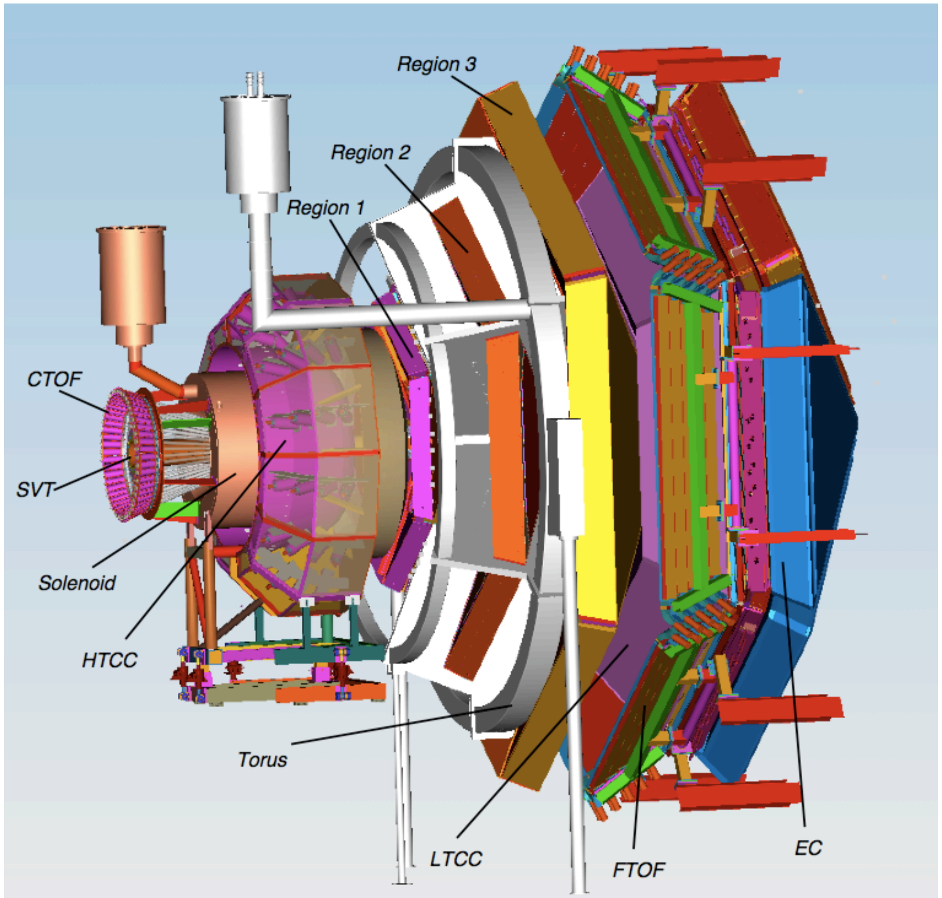
CLAS12 JLab Upgrade to 12 GeV

Luminosity > $10^{35}cm^{-2}s^{-1}$

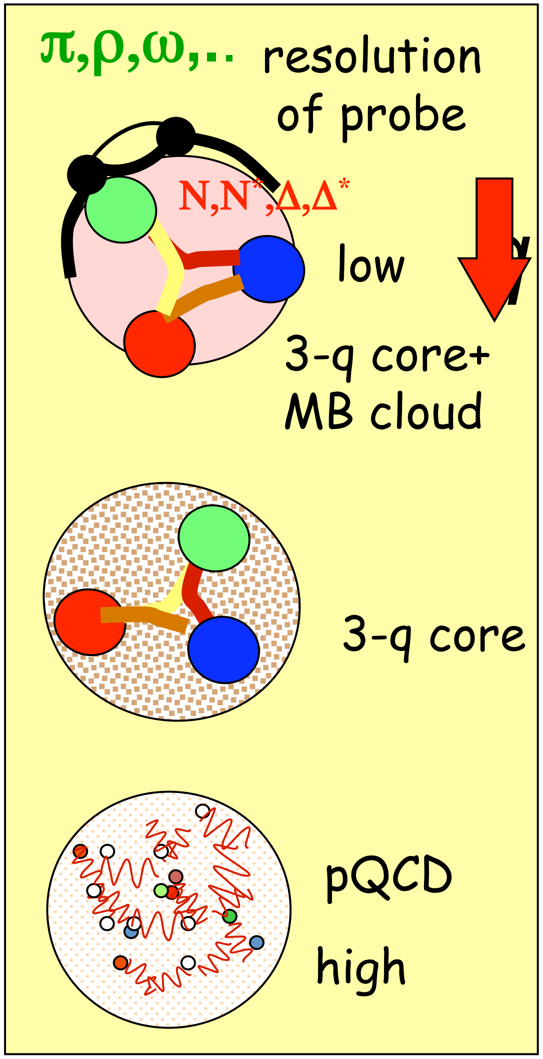
- General Parton Distributions
- Transverse parton distributions
- Longitudinal Spin Structure
- N* Transition Form Factors
- Heavy Baryon Spectroscopy
- Hadron Formation in Nuclei

Forward Tracker, Calorimeter, Particle ID

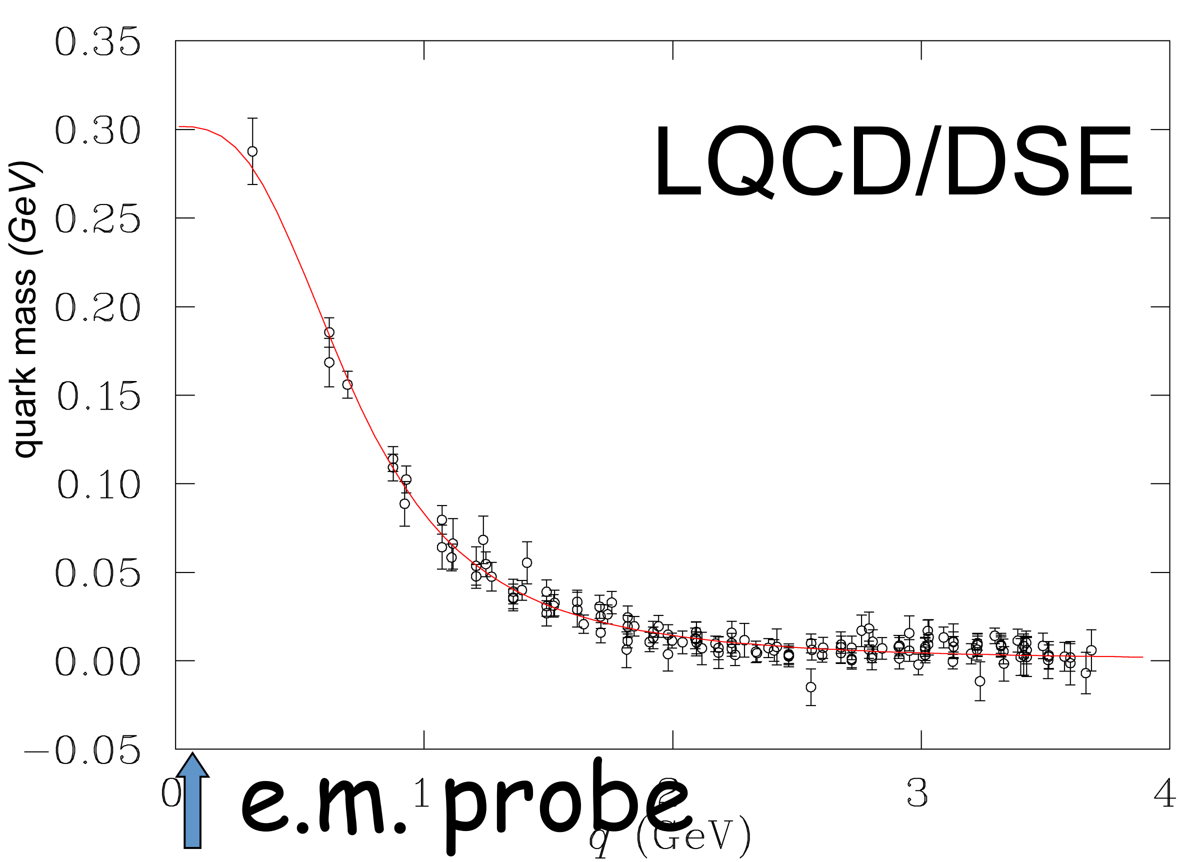
Solenoid, ToF, Central Tracker



Hadron Structure with Electromagnetic Probes

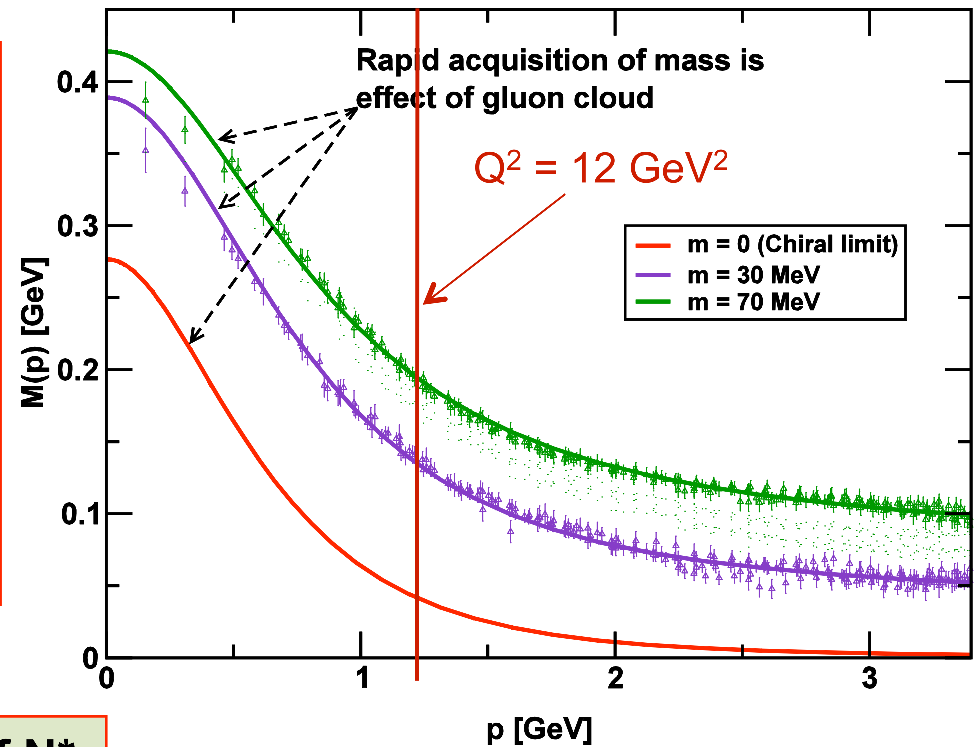


Allows to address central question:
What are the relevant degrees-of-freedom at varying distance scale?



Physics Objectives in the N* Studies with CLAS12

- explore the interactions between the dressed quarks, which are responsible for the formation for both ground and excited nucleon states.
- probe the mechanisms of light current quark dressing, which is responsible for >97% of nucleon mass.



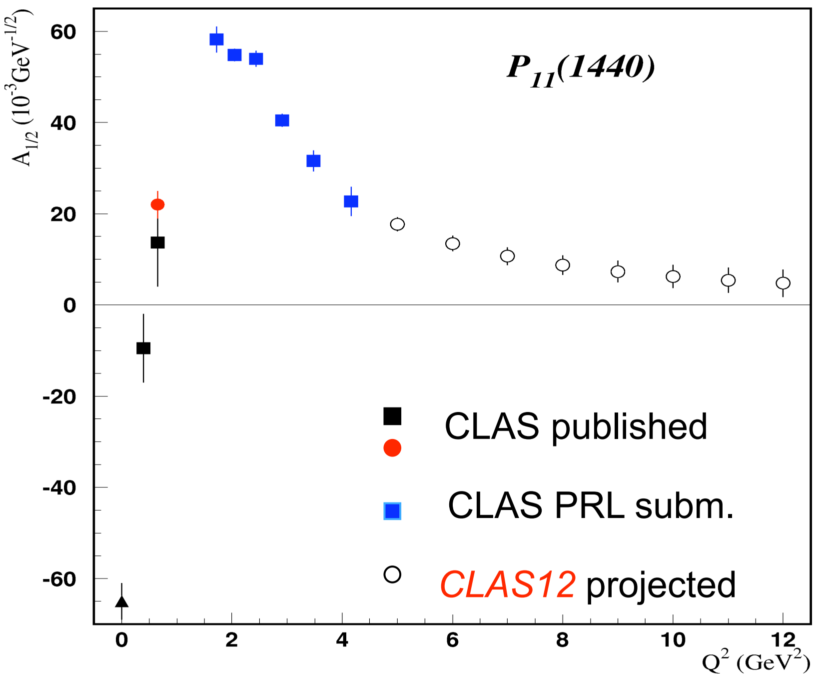
Approaches for theoretical analysis of N* electrocouplings: LQCD, DSE, Ads/CFT relativistic quark models. See details in the 62-page White Paper of EmNN* JLAB Workshop, October 13-15, 2008: http://www.jlab.org/~mokeev/white_paper/
Aznauryan *et al.*, arXiv:0907.1901[nucl-th]

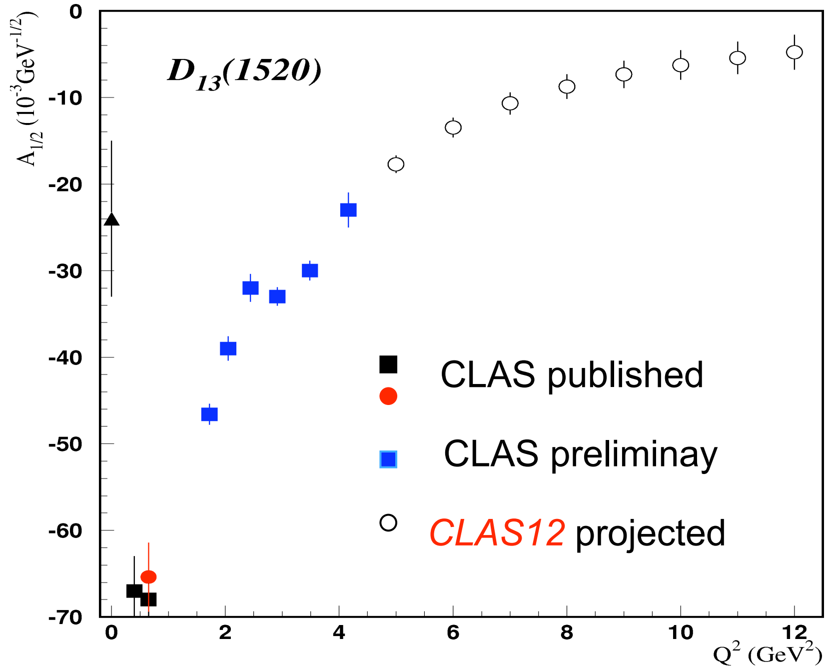
Independent QCD Analyses
Line Fit: DSE Points: LQCD

Need to multiply by $3p^2$ to get the Q^2 per quark

CLAS12 Projections for N* Transitions

For the foreseeable future, CLAS12 will be the only facility worldwide, which will be able to access the N* electrocouplings in the Q^2 regime of 5 GeV^2 to 10 GeV^2, where the quark degrees of freedom are expected to dominate. Our experimental proposal "*Nucleon Resonance Studies with CLAS12*" was approved by PAC34 for the full 60-day beamtime request. http://www.physics.sc.edu/~gothe/research/pub/nstar12-12-08.pdf.





The results from our N* experiments will be used by the Physics Analysis Center and the Theory Support Group to provide

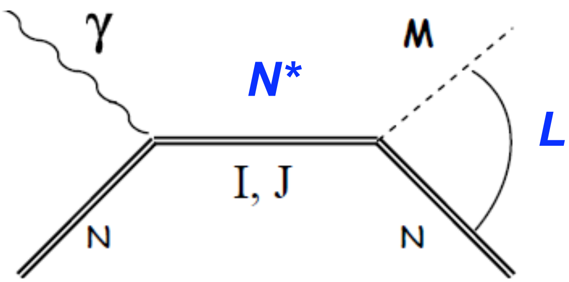
- access to the dynamics of non-perturbative strong interactions among dressed quarks and their emergence from QCD and the subsequent formation into baryon resonances;
- information on how the constituent quark mass arises from a cloud of low-momentum gluons, which constitute the dressing to the current quarks. [N.B. More than 98% of the N* mass is generated non-perturbatively through dynamical chiral symmetry breaking – that is confinement in the baryon sector comes about from QCD];
- enhanced capabilities for exploring the behavior of the universal QCD β-function in the infrared regime.

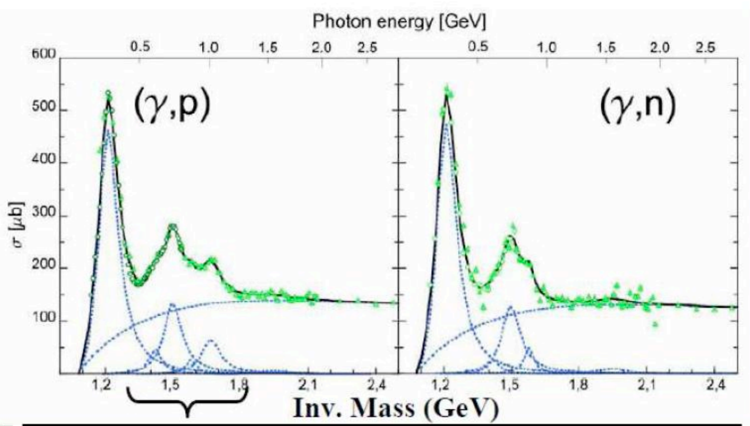
Thank you

Grazie Danke მადლობა Merci Hvala
شكرا جزيلا Спасибо ありがとうございます
Obrigado 谢谢 Takk 고맙습니다 Gracias

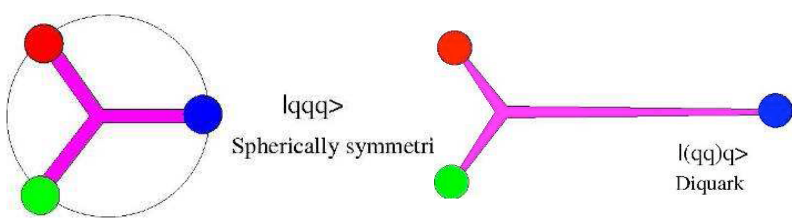
BACKUP SLIDES

Motivation





Second resonance region: $P_{11}(1440)$, $D_{13}(1520)$, $S_{11}(1535)$

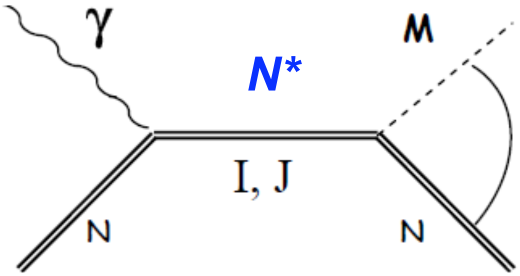


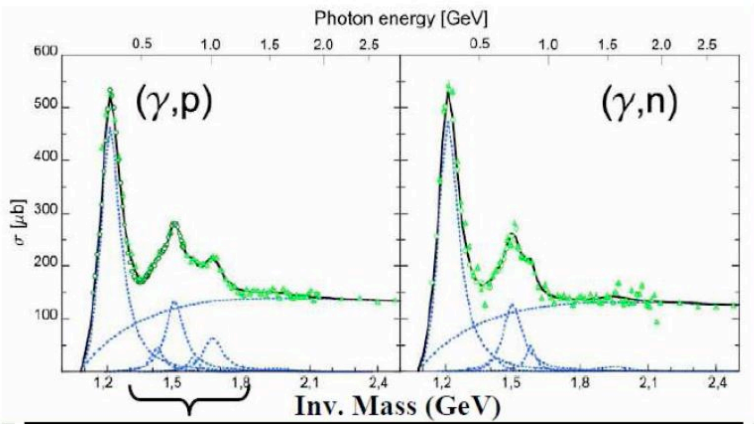
$L_{2I\,2J}$

N*	Status	SU(6) ⊗ O(3)	Parity	Δ*	Status	SU(6) ⊗ O(3)
P11(938)	****	$(56,0^+)$	+	P33(1232)	****	$(56,0^+)$
S11(1535)[c]	****	$(70,1^-)$				
S11(1650)	****	$(70,1^-)$		S31(1620)	****	$(70,1^-)$
D13(1520)[c,d]	****	$(70,1^-)$	−	D33(1700)	****	$(70,1^-)$
D13(1700)	***	$(70,1^-)$				
D15(1675)	****	$(70,1^-)$				
P11(1520)	****	$(56,0^+)$		P31(1875)	****	$(56,2^+)$
P11(1710)[b]	***	$(70,0^+)$		P31(1835)		$(70,0^+)$
P11(1880)		$(70,2^+)$				
P11(1975)		$(20,1^+)$				
P13(1720)[b,c]	****	$(56,2^+)$		P33(1600)	***	$(56,0^+)$
P13(1870)[b]	**	$(70,0^+)$		P33(1920)	***	$(56,2^+)$
P13(1910)[a]		$(70,2^+)$	+	P33(1985)		$(70,2^+)$
P13(1950)		$(70,2^+)$				
P13(2030)		$(20,1^+)$				
F15(1680)[c,d]	****	$(56,2^+)$		F35(1905)	****	$(56,2^+)$
F15(2000)[a]	**	$(70,2^+)$		F35(2000)	**	$(70,2^+)$
F15(1995)		$(70,2^+)$				
F17(1990)	**	$(70,2^+)$		F37(1950)	****	$(56,2^+)$

J.J.Dudek and R.G.Edwards, Hybrid Baryons in QCD
arXiv:1201.2349[hep-ph] (January 10, 2012)

Motivation

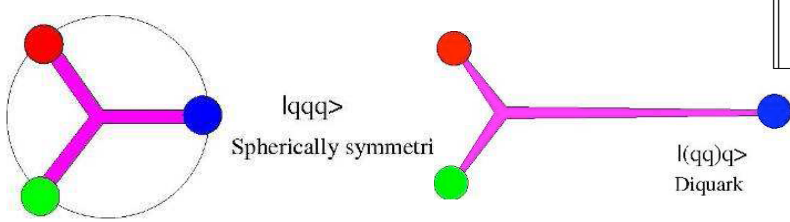




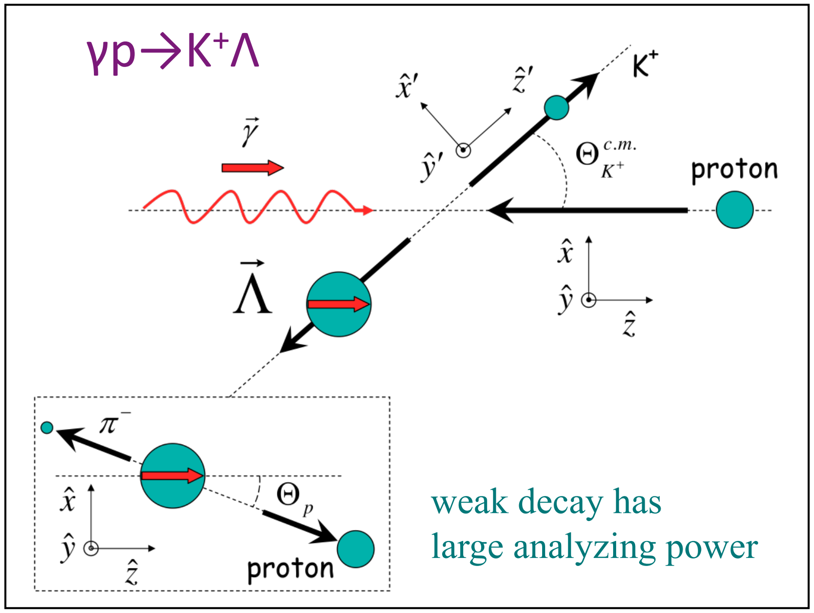
Second resonance region: $P_{11}(1440)$, $D_{13}(1520)$, $S_{11}(1535)$

$L_{2I\ 2J}$

Mass	J^{π}	γp	πN	$\pi\Delta$	ρN	ωN	Total
N(1490)	$1/2^-$	1.3	28.	2.9	40.	0.	98.
N(1655)	$1/2^-$	0.72	76.	67.	102.	1.4	262.
N(1535)	$1/2^-$	0.58	85.	52.	27.	0.	164.
N(1745)	$3/2^-$	0.009	13.	317.	26.	2.9	360.
N(1670)	$5/2^-$	0.013	30.	86.	5.3	0.	130.
N(1405)	$1/2^+$	0.026	46.	5.8	0.1	0.	52.
N(1705)	$1/2^+$	0.23	45.	13.	36.	0.8	108.
N(1890)	$1/2^+$	0.057	19.	12.	22.	37.	96.
N(2055)	$1/2^+$	0.009	1.4	3.2	1.7	32.	39.
N(1710)	$1/2^+$	1.0	42.	4.4	156.	32.	242.
N(1870)	$3/2^+$	0.027	10.	19.	2.3	98.	149.
N(1955)	$3/2^+$	0.021	1.2	88.	56.	90.	236.
N(1980)	$3/2^+$	0.031	1.2	96.	71.	55.	223.
N(2060)	$3/2^+$	0.0001	0.3	31.	15.	98.	145.
N(1715)	$5/2^+$	0.29	50.	4.4	20.	1.4	77.
N(1955)	$5/2^+$	0.24	0.2	64.	67.	184.	324.
N(2025)	$5/2^+$	0.001	1.7	67.	66.	180.	316.
N(1955)	$7/2^+$	0.006	9.6	36.	18.	53.	126.



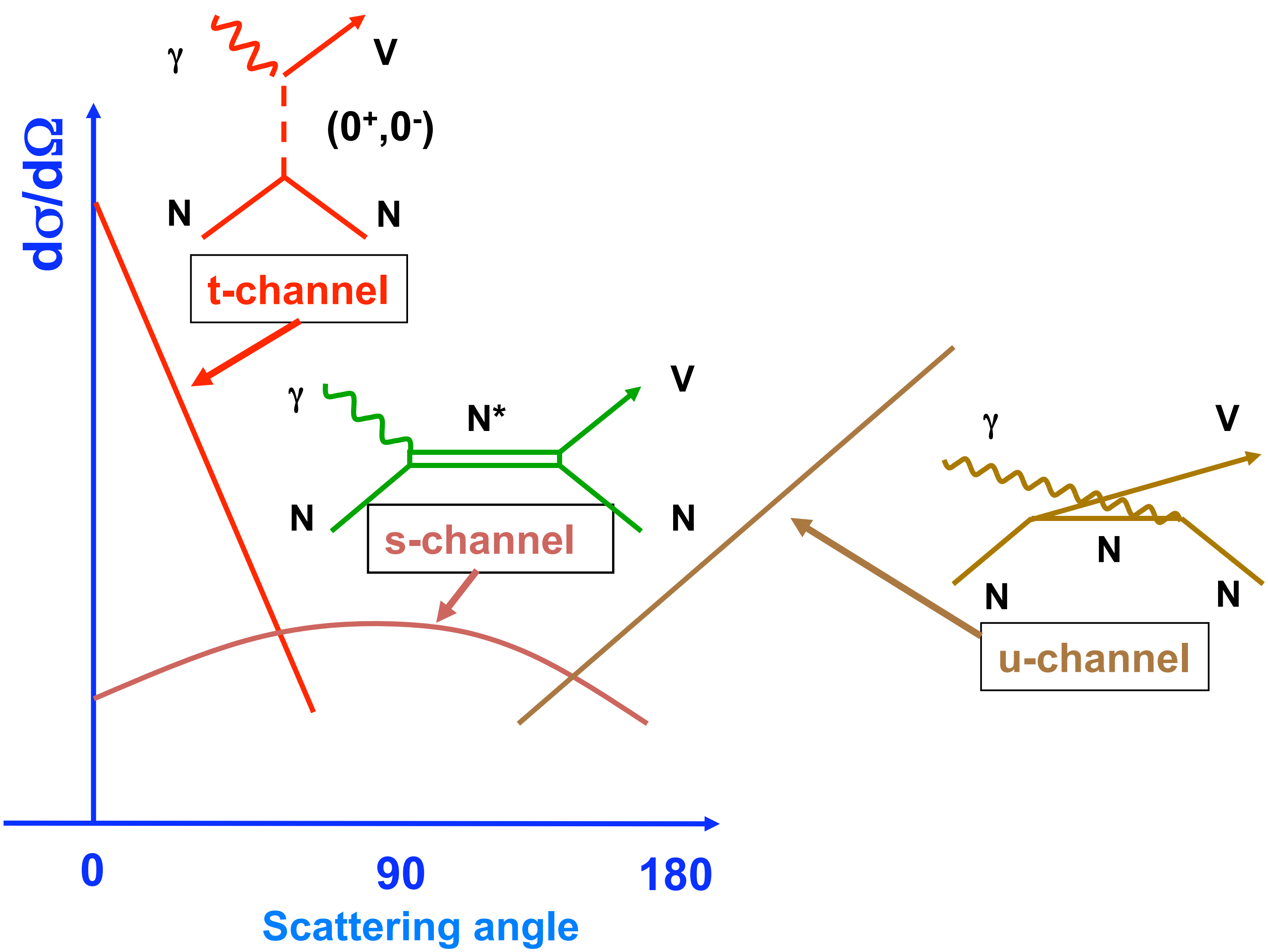
FROST/HD $\vec{\gamma}\vec{N} \rightarrow \pi N, \eta N, K\vec{\Lambda}, K\vec{\Sigma}, N\pi\pi$



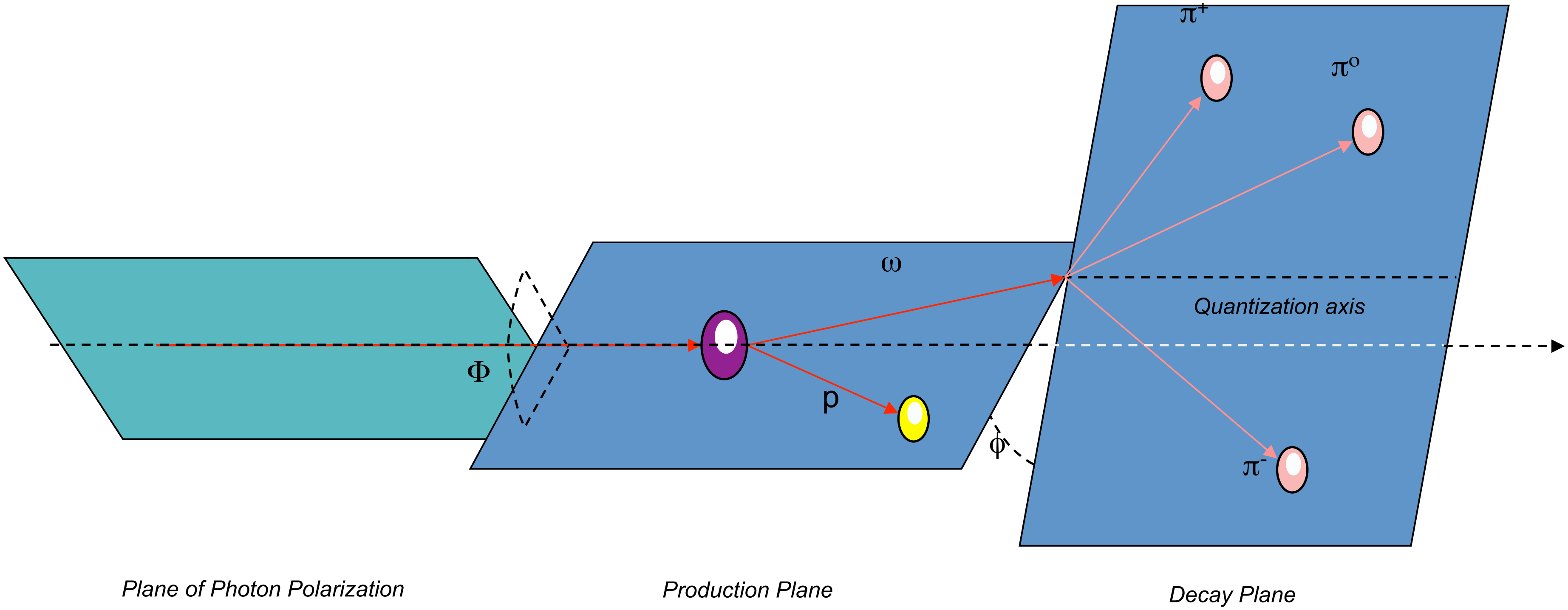
- Process is described by 8 complex, parity conserving amplitudes (4 independent amplitudes).
- 8 well-chosen measurements are needed to determine amplitude
- For hyperon finals state, 16 observables are measured in CLAS ➠ large redundancy in determining the photo-production amplitudes ➠ allows many cross checks and increased accuracy
- 8 observables measured in reactions without recoil polarization

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		$O_{x'}$	

Kinematic features vector-meson photoproduction



The Decay Angular Distribution



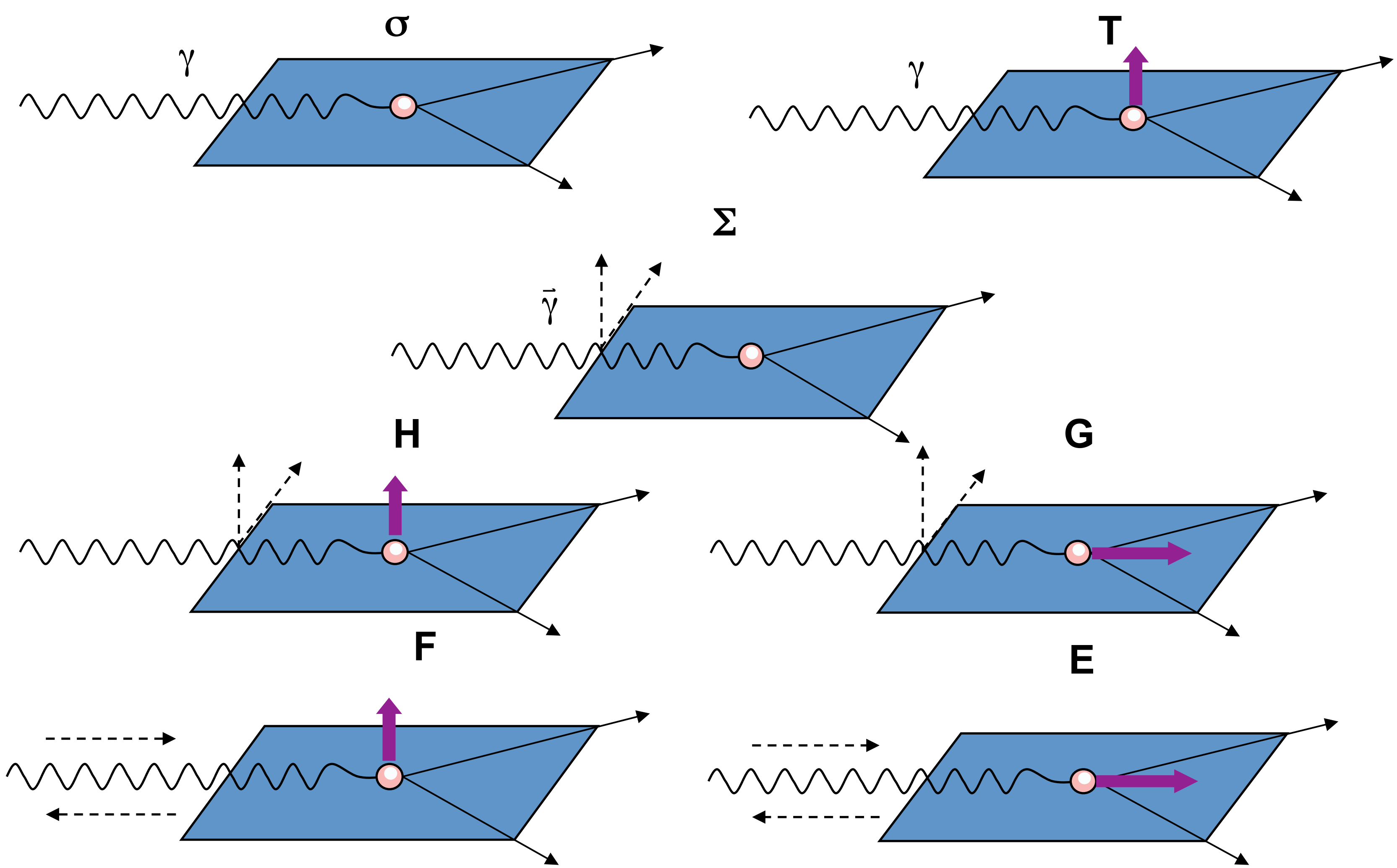
P_γ = degree of polarization of the photon

Φ = the angle of photon polarization vector wrt the production plane

θ = polar angle of the decay plane

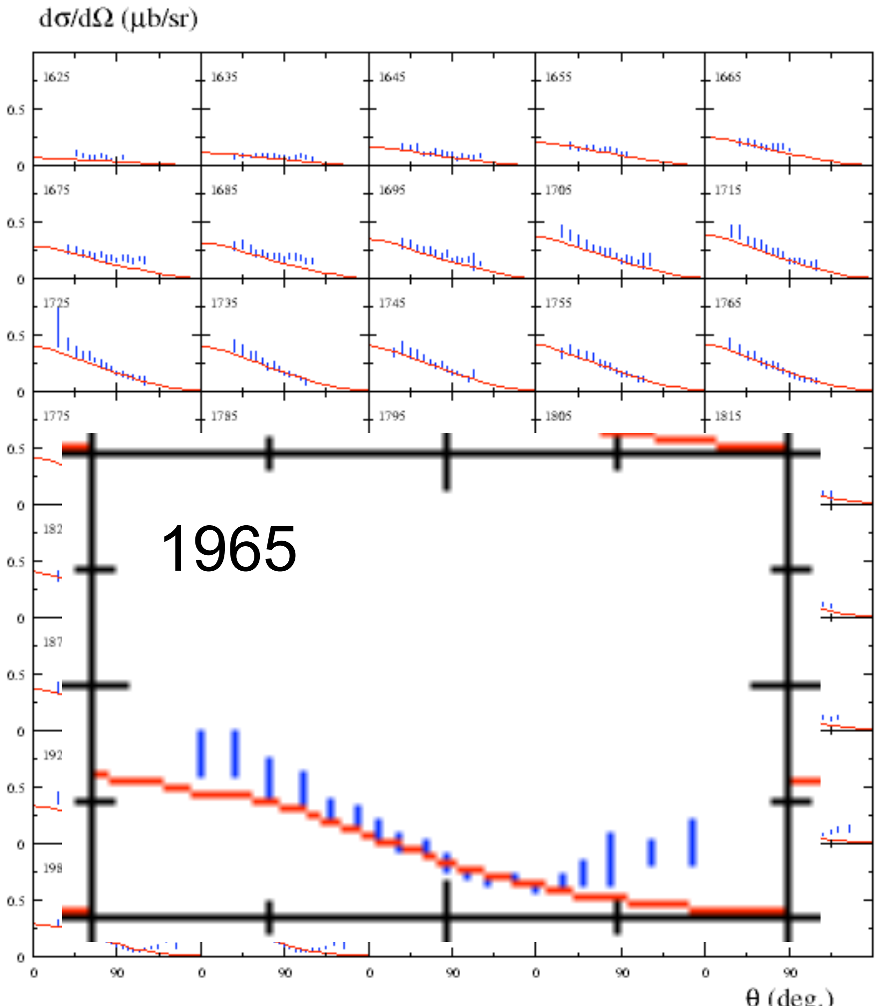
ϕ = azimuthal angle of the decay plane

Photon and Target Polarization

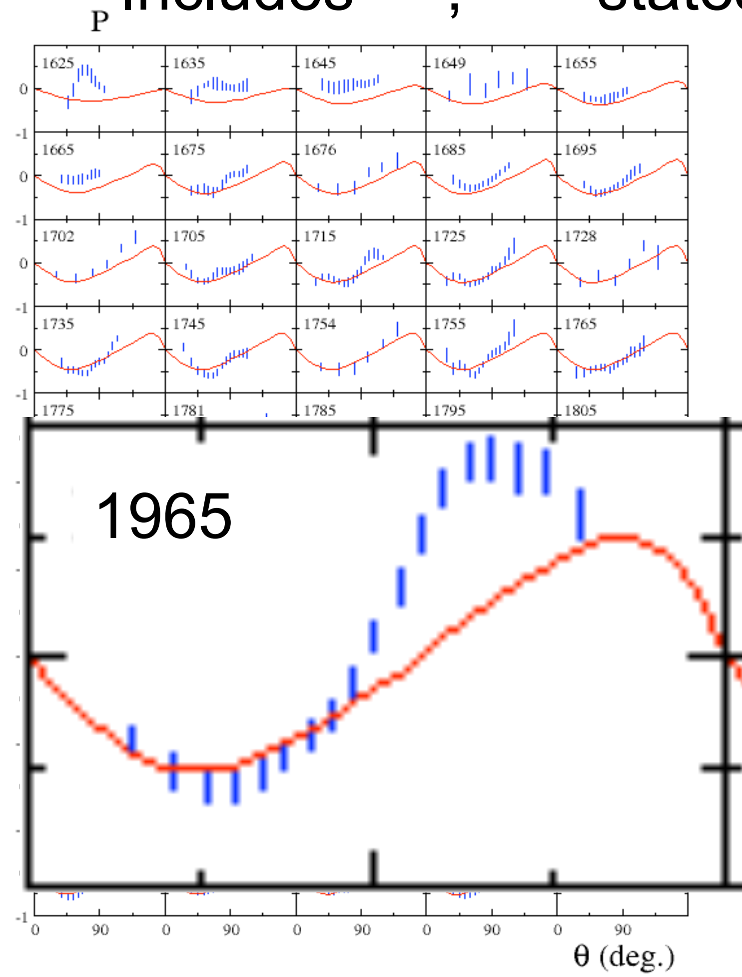


Fit to K⁺Λ with PDG2010 states < 2 GeV

EBAC group: Kamano, Nakamura, Lee, Sato (2012)



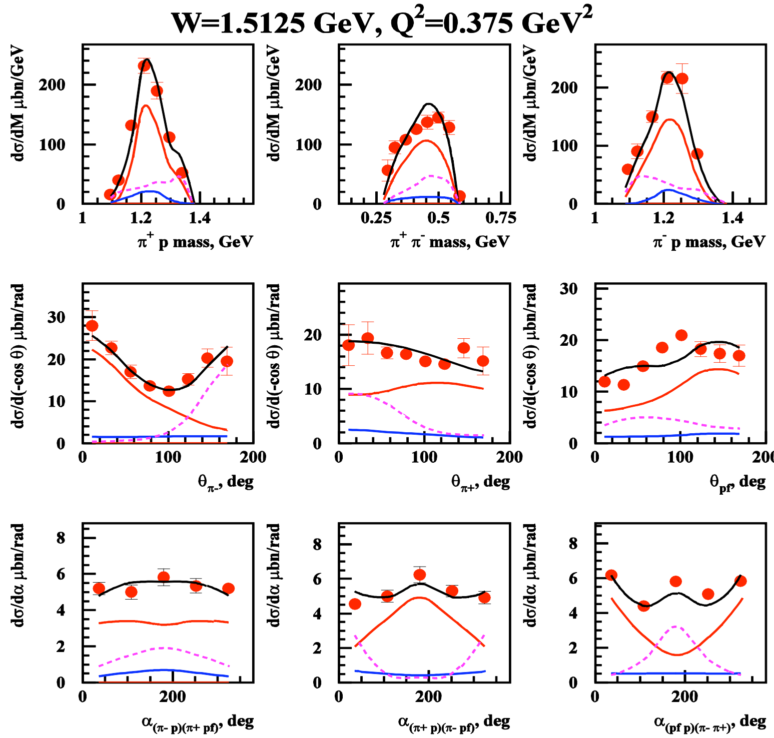
Includes ***, **** states



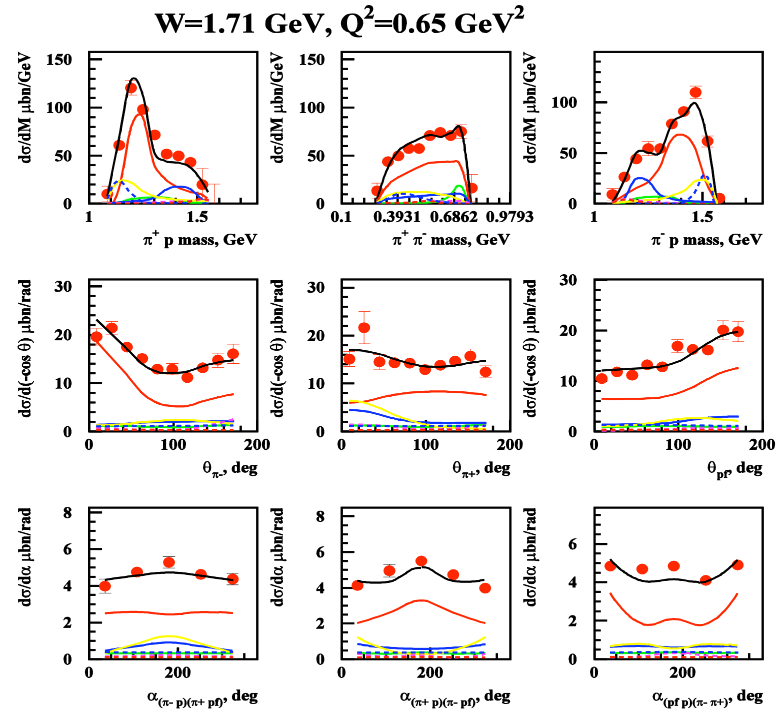
PDG states insufficient to fit KΛ data

JM Mechanisms as Determined by the CLAS 2π Data

G.V.Fedotov *et al.,* PRC 79 (2009), 015204



M.Ripani *et al.*, PRL 91 (2003), 022002



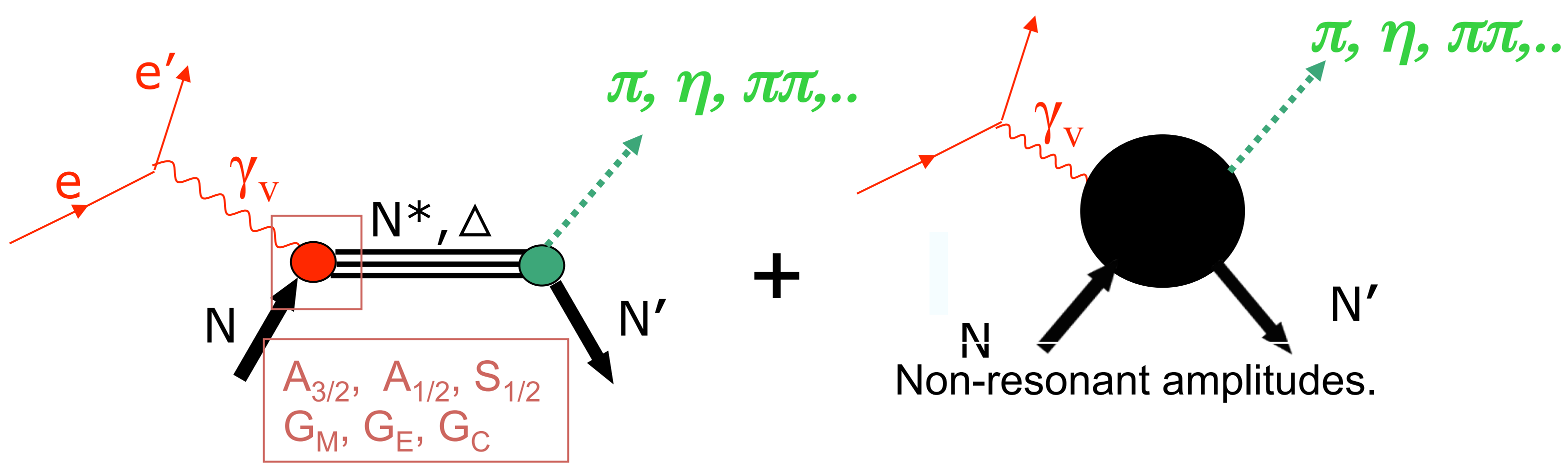
Full JM calc — $\pi^+\Delta^0$ — $\pi^+D_{13}(1520)$ — $\pi^+F_{15}(1685)$

$\pi^-\Delta^{++}$ — 2π direct — ρp

- Any contributing mechanism has considerably different shapes of cross sections in various observables defined by the particular behavior of their amplitudes.
- A successful description of all observables allows us to check and to establish the dynamics of all essential contributing mechanisms.

How N* electrocouplings can be accessed

- **Isolate the resonant part of production amplitudes by fitting the measured observables within the framework of reaction models, which are rigorously tested against data.**
- **These N* electrocouplings can then be determined from resonant amplitudes under minimal model assumptions.**

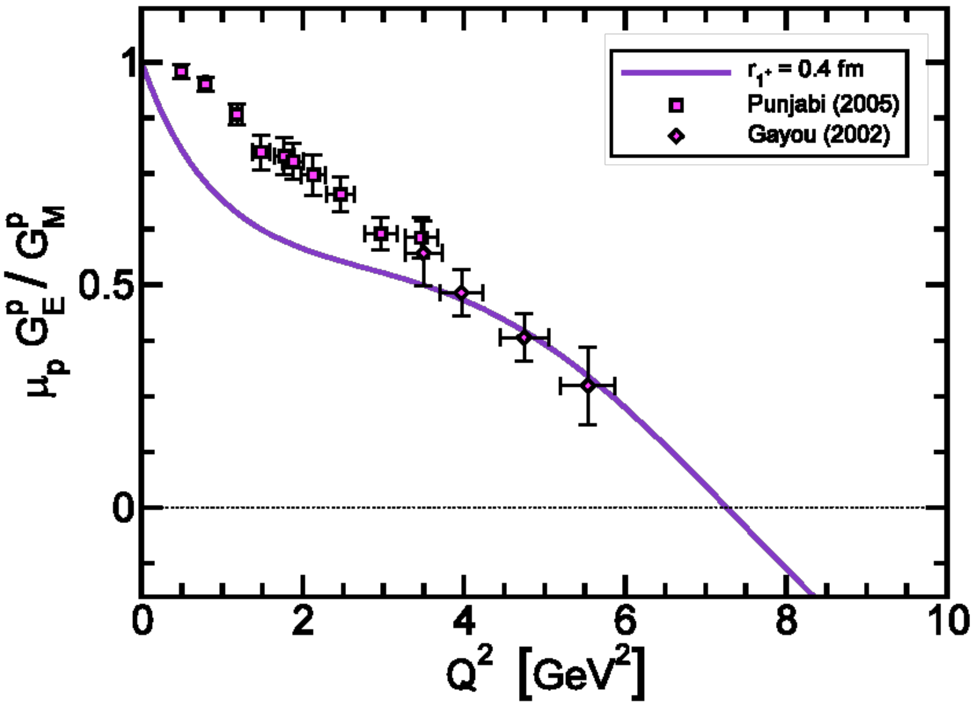


Consistent results on N* electrocouplings obtained in analyses of various meson channels (e.g. πN, ηp, $\pi\pi N$) *with entirely different non-resonant amplitudes* will show that they are determined reliably

Advanced coupled-channel analysis methods are being developing at EBAC: B.Julia-Diaz, T-S.H.Lee *et al.*, PRC76, 065201 (2007);T.Sato and T-S.H.Lee arXiv:0902.353[nucl-th]

Dyson-Schwinger Equation (DSE) Approach

DSE provides an avenue to relate N* electrocouplings at high Q^2 to QCD and to test the theory's capability to describe the N* formation based on QCD.



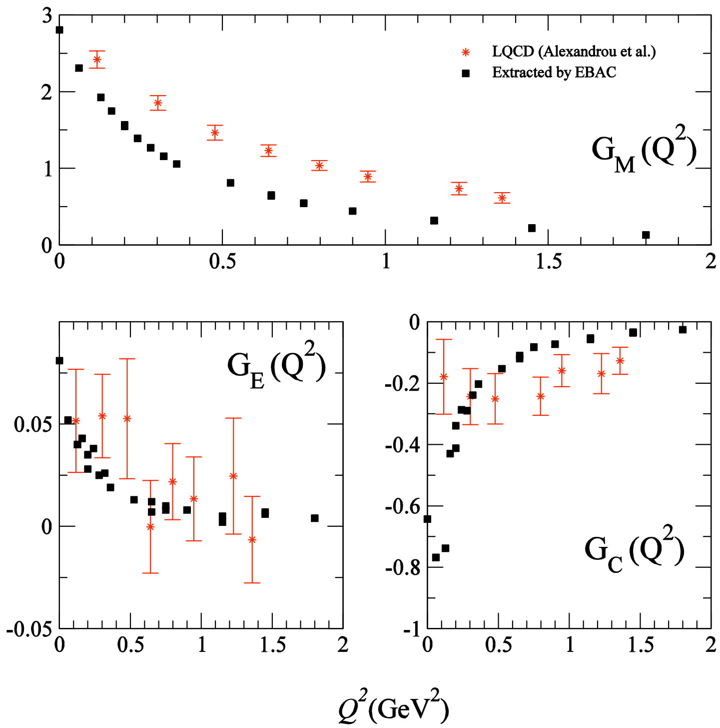
DSE approaches provide a link between dressed quark propagators, form factors, and scattering amplitudes and QCD.

N* electrocouplings can be determined by applying Bethe-Salpeter /Fadeev equations to 3 dressed quarks while the properties and interactions are derived from QCD.

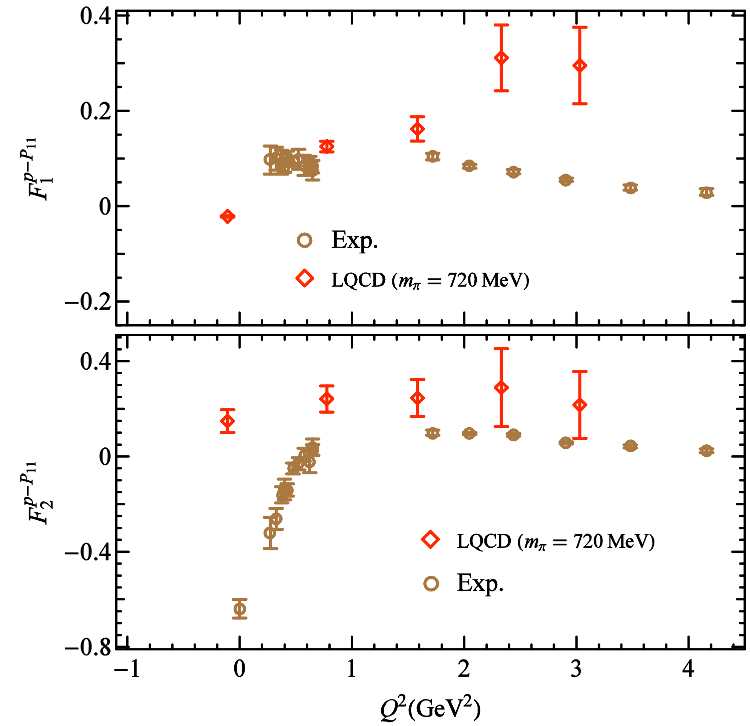
By the time of the upgrade DSE electrocouplings of several excited nucleon states will be available as part of the commitment of the Argonne NL and the University of Washington.

Current Status of Lattice QCD

$\Delta(1232)P_{33}$



$N(1440)P_{11}$



LQCD calculations of the $\Delta(1232)P_{33}$ and $N(1440)P_{11}$ transitions have been carried out with large π-masses.

By the time of the upgrade LQCD calculations of N* electrocouplings will be extended to Q^2 = 10 GeV^2 near the physical π-mass as part of the commitment of the JLAB LQCD and EBAC groups in support of this proposal.