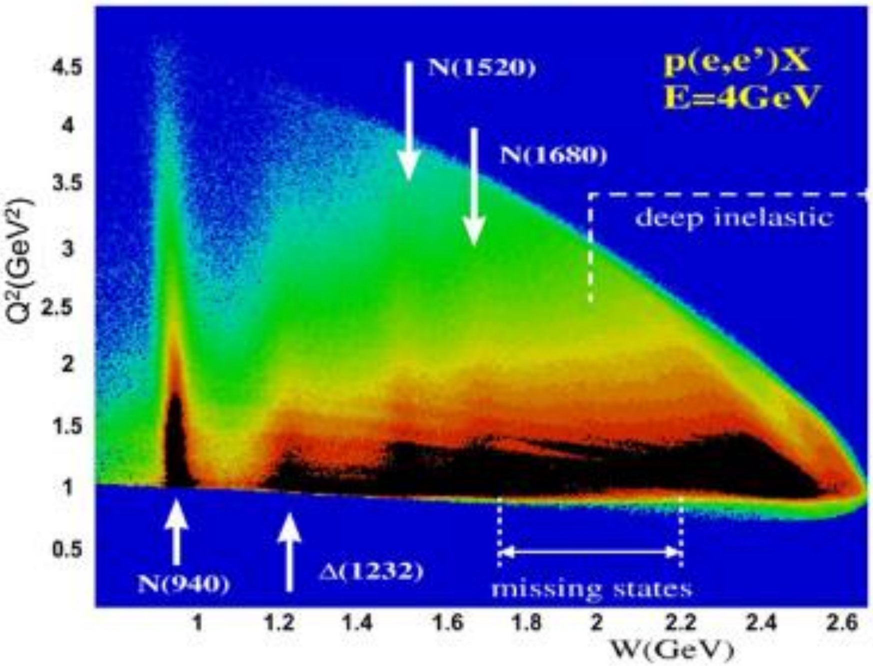
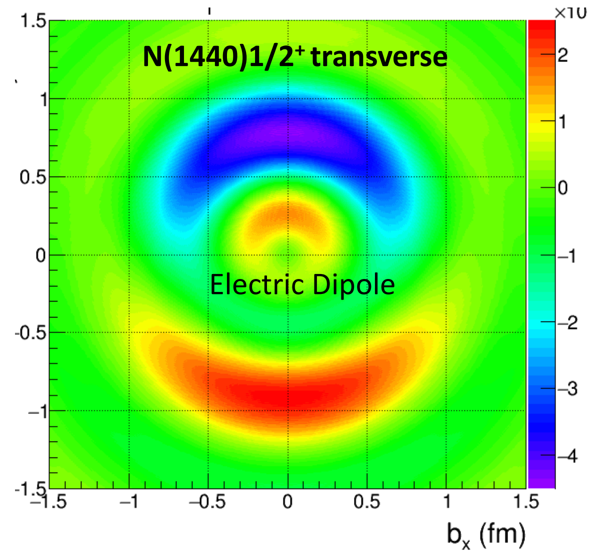
New Results on the Nucleon Resonance Spectrum and Structure from Photo- and Electroproduction Experiments





V.I. Mokeev,
Jefferson Laboratory

The talk outline:

- advances in the exploration of the N* spectrum;
- N* structure from exclusive electroproduction as a window to strong QCD dynamics;
- future prospects in experiments with the CLAS12 detector in the 12 GeV era at Jefferson Lab.

Office of Science

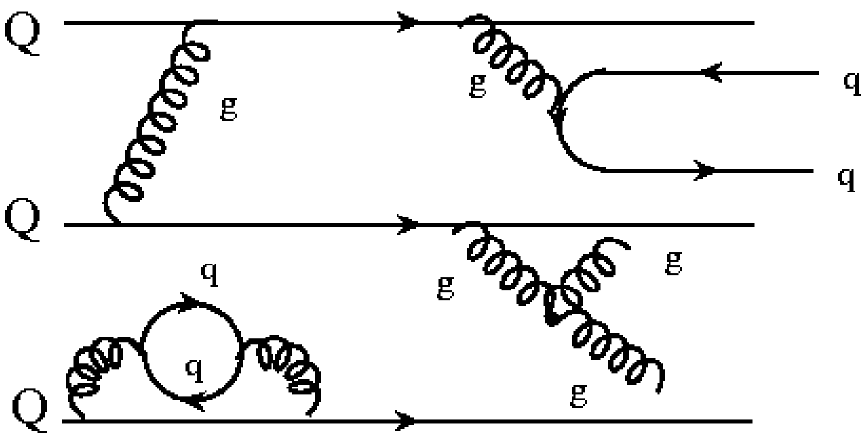
APS April Meeting 2018, Session C05: From QCD to the Deuteron, April 14 — 17, 2018; Columbus, Ohio

Nucleons as the Building Blocks of Hadronic Matter

- **At the strong interaction time scale (~10^{-22} sec), nucleons, protons and neutrons, along with pions are the stable elementary particles produced after the Big Bang**

- **Nucleons and atomic nuclei account for most of the visible mass in the Universe**

The structure of the nucleon ground states



Three valence current quarks (Q) embedded in a sea of gauge gluons (g) and quark+antiquark pairs

Particular features of nucleon structure:

•the current quarks and gauge gluons are in permanent creation/annihilation processes;

• relativistic objects moving with velocities comparable with the velocity of light;

•quarks and gluons are always confined inside the hadrons; they are never free.

Such a complex composite system should possess a spectrum of excited states.

Understanding the nature of quark-gluon confinement requires a combined studies of the ground and excited nucleon states.

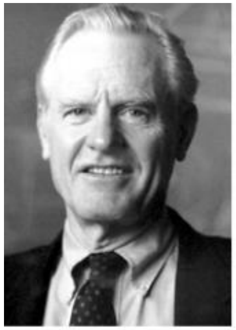
Nobel Prize Achievements in the Ground and Excited Nucleon Exploration

R. Hofstadter

1961

"for his pioneering studies of electron scattering in atomic nuclei and for his thereby achieved discoveries concerning the structure of the nucleons"

J.I. Friedman



H.W. Kendall

R.E. Taylor

1990

"for their pioneering investigations concerning deep inelastic scattering of electrons on protons and bound neutrons, which have been of essential importance for the development of the quark model in particle physics".

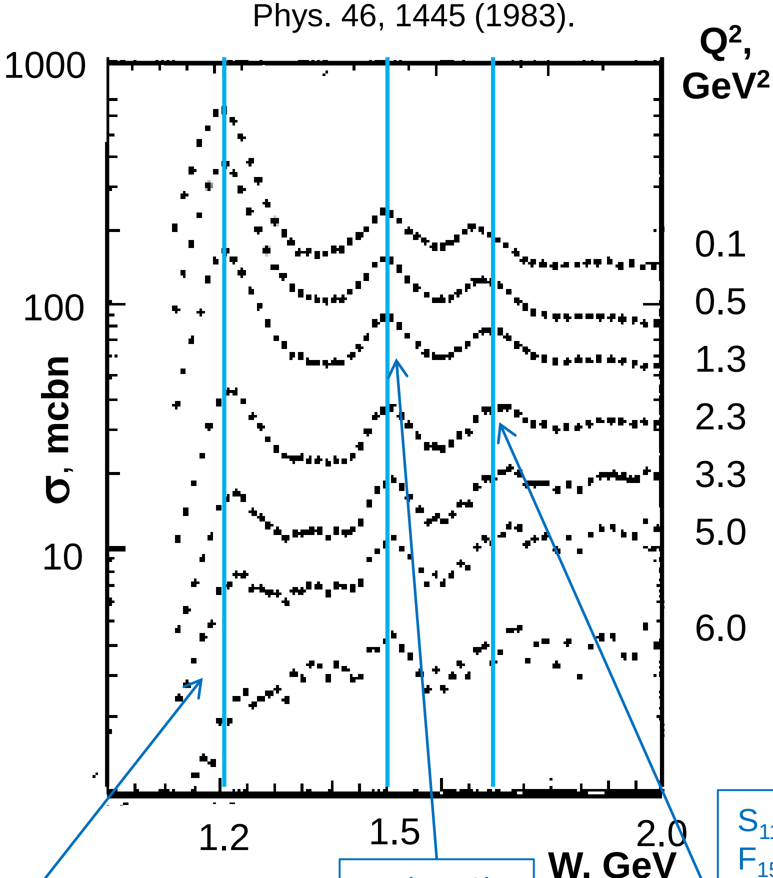
L.W. Alvarez

1968

"for his decisive contributions to elementary particle physics, in particular the discovery of a large number of resonance states, made possible through his development of the technique of using hydrogen bubble chamber and data analysis".

Nucleon Resonances (N*) in Inclusive Processes with Electron and Hadron Beams

Nucleon resonances in total virtual photon cross section
F. Foster and G.Hughes, Rep. Progr. Phys. 46, 1445 (1983).

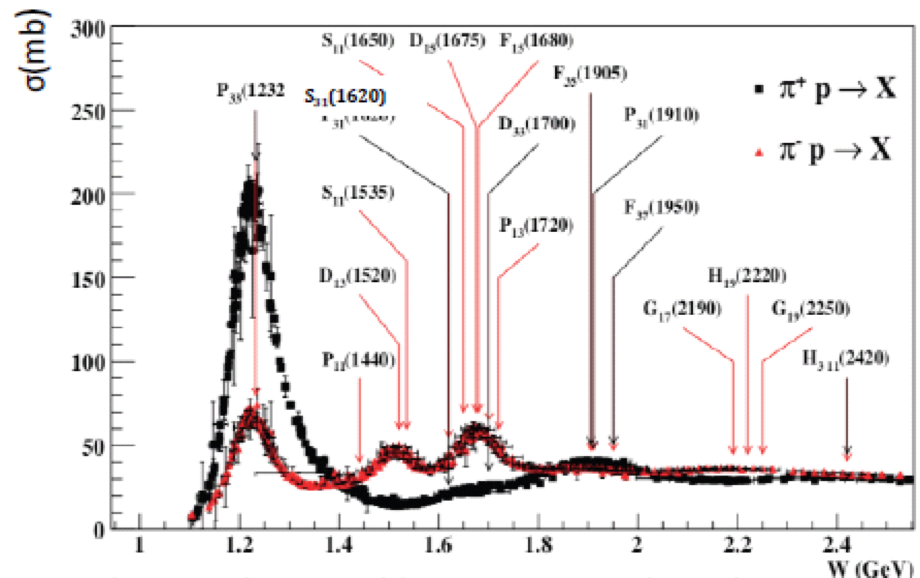


$P_{33}(1232)$

$P_{11}(1440)$, $D_{13}(1520)$, $S_{11}(1535)$, $S_{31}(1620)$

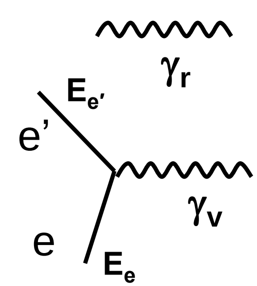
$S_{11}(1650)$, $F_{15}(1685)$, $D_{33}(1700)$, $P_{11}(1710)$, $P_{13}(1720)$, $3/2^{+}(1720)$.

Nucleon resonances from hadroproduction data



The experiments with electromagnetic probes are:

- **the only source of information on the structure of excited nucleon states;**
- **promising tool for new baryon state search and high-lying resonance studies**



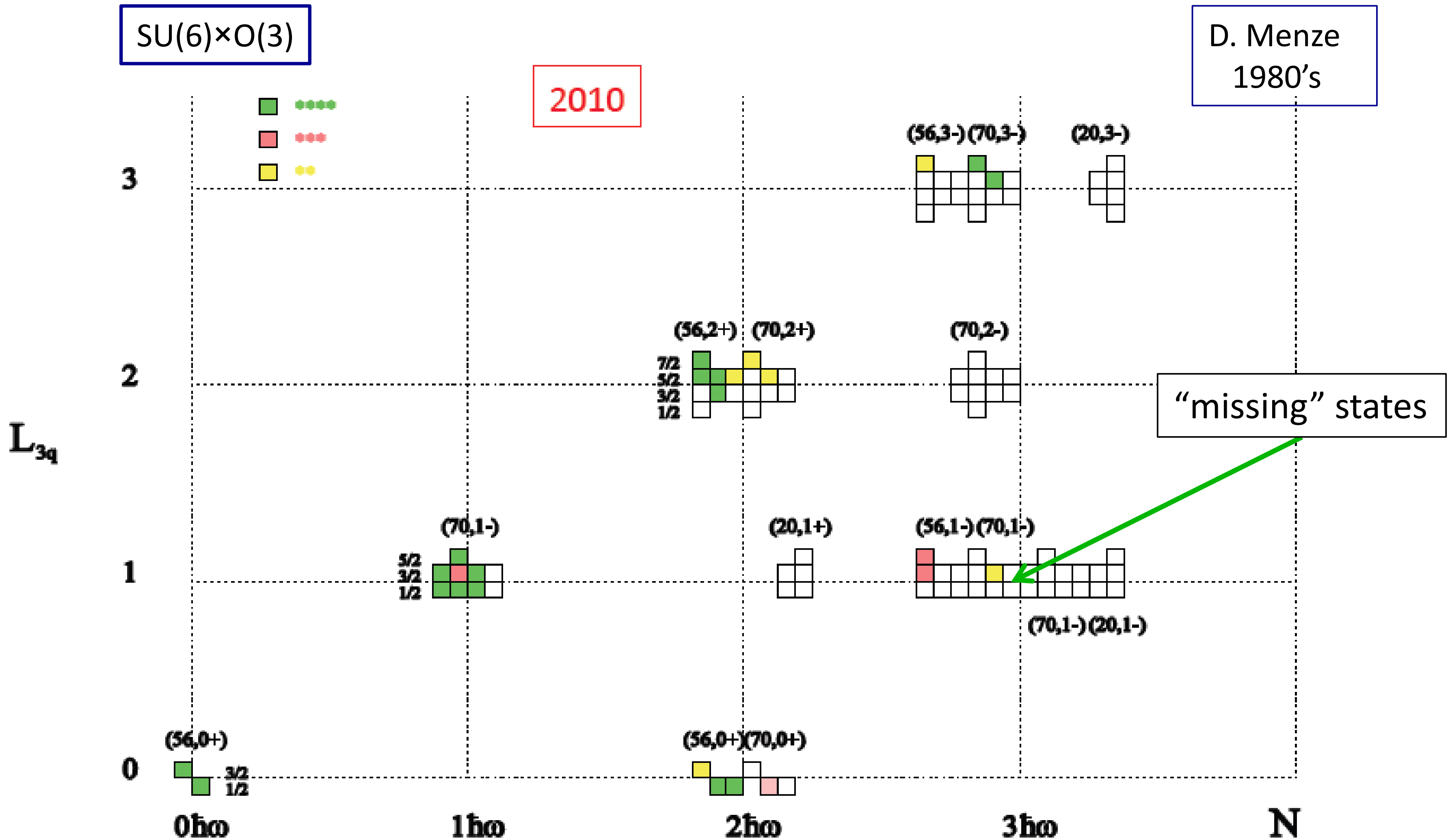
q^2=0 **real photons** → **N* Spectrum**

virtual photons
$E^2_{\gamma_v}-\vec{q}^{\,2}_{\gamma_v} = q^2$ → **N* Structure**

$Q^2 = -q^2 = 4E_eE_{e'}\sin^2(\frac{\vartheta_{e'}}{2})$

sensitivity to the distances ~$\frac{1}{\sqrt{Q^2}}$, GeV^{-1}

SU(6)xO(3) Spin-Flavor Symmetry and ``Missing" Resonances



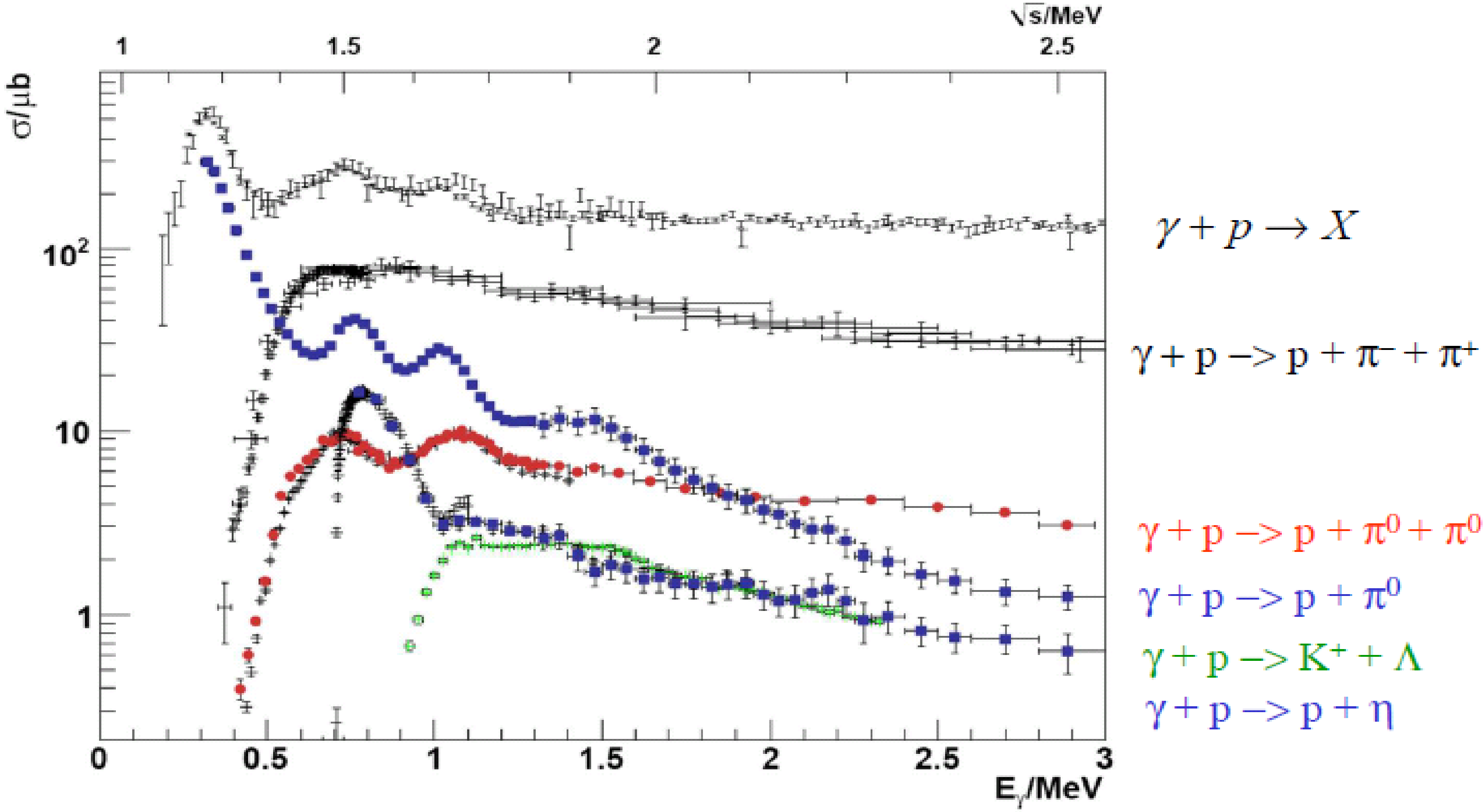
Studies of the N*-spectrum were driven by a guess for the ``missing" baryon states expected from underlying SU(6) xO(3) symmetry

Exclusive Photoproduction in the Nucleon Resonance Region

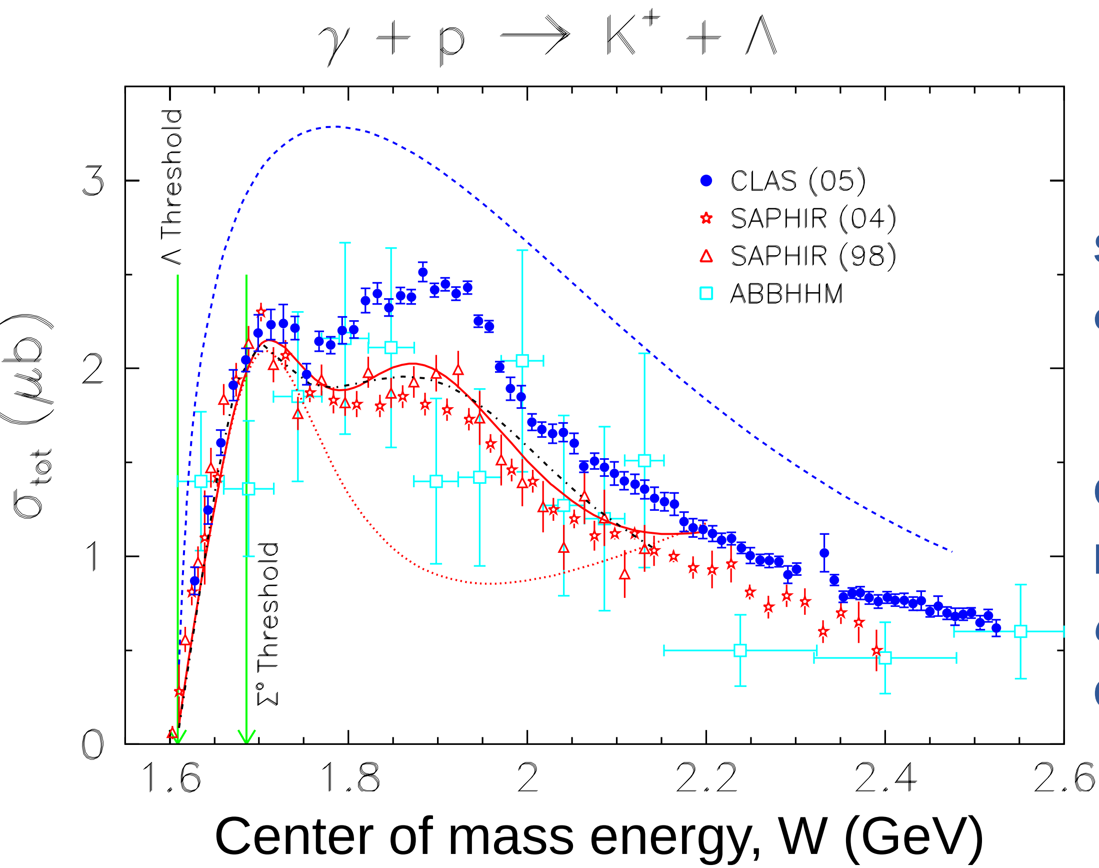
Common effort at ELSA, JLab and MAMI.

Combination of continuous electron beams and detectors of ~4π acceptance allows us to determine types of all final particles and their 4-momenta in each reaction.

Most exclusive photoproduction channels in the resonance region were studied.



New States in $K^+\Lambda$ Photoproduction: Suggestive Bump at W~1.9 GeV



SAPHIR data (1998) triggered discussion of "missing" resonances.

CLAS got into the game (2005-2007)

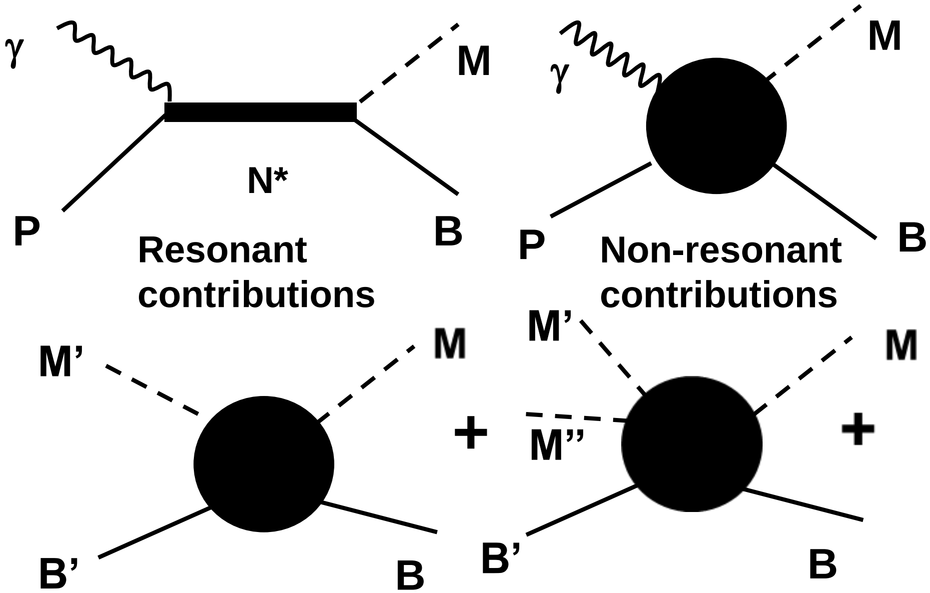
First CLAS measurements (g1c):

dσ/dΩ, P, Cx, Cz

Confirmed bump around 1.9 GeV

Connecting Nucleon Resonance Properties to the Photoproduction Observables

γ + P→Meson (M) + Baryon (B)

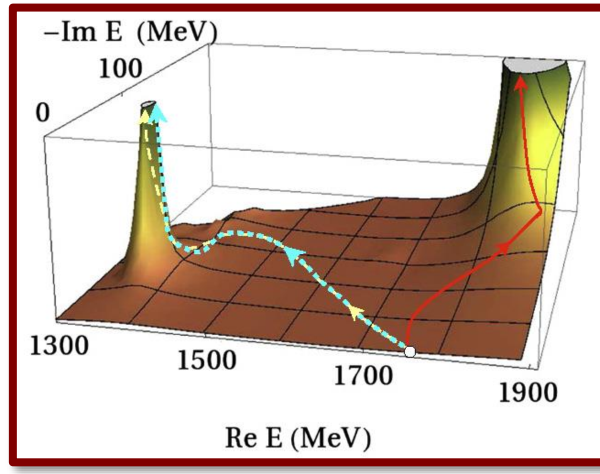


Hadronic final state interactions (FSI) affect both resonant/non-resonant contributions

$$T_{full} = T_{res} + T_{non-res}$$

Breit-Wigner parameterization:

$$T_{res} = \frac{T(R \to MB)\,T(\gamma p \to R)}{M_{N^*}^2 - W^2 - i\Gamma_{N^*}(W) M_{N^*}}$$



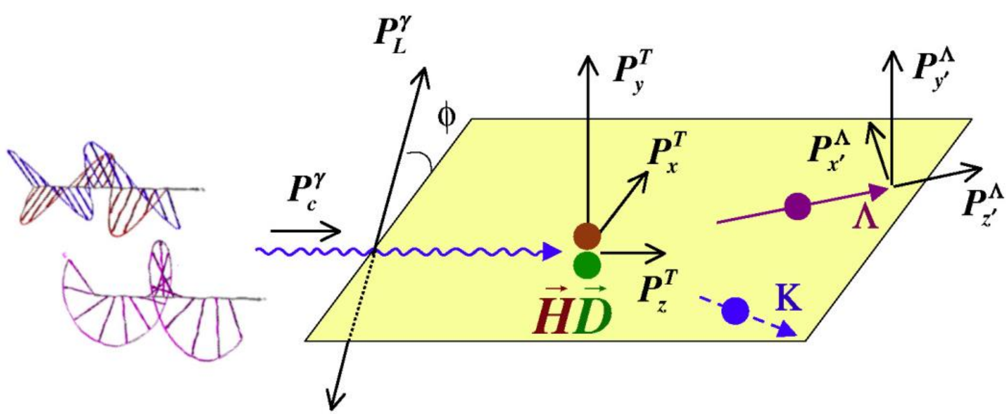
- **Constrain exclusive photoproduction amplitudes by fitting them to the data on differential cross sections and polarization asymmetries.**
- **Take into account the FSI effects→ Global multi-channel analyses of all available exclusive photo-/hadroproduction channels.**
- **Make analytical continuation of reaction amplitudes into the complex energy plane and:**

a) locate poles → **Resonance masses (M_{N^*}) and total widths (Γ_{N^*}) ;**
b) determine residues → **Resonance photocouplings and partial hadronic decay widths.**

Observables in 2-body Meson-Baryon Photoproduction Channels

[SHKL, J Phys G**38** (11) 053001]

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		$T_{z'}$		$L_{z'}$
$P_L^\gamma \sin(2\phi_\gamma)$		H		G	$O_{x'}$		$O_{z'}$		$C_{z'}$		E		F		$-C_{x'}$	
$P_L^\gamma \cos(2\phi_\gamma)$	$-\Sigma$		$-P$			$-T$		$-L_{z'}$		$T_{z'}$		$-\sigma_0$		$L_{x'}$		$-T_{x'}$
circular P_c^γ		F		$-E$	$C_{x'}$		$C_{z'}$		$-O_{z'}$		G		$-H$		$O_{x'}$	



- ***16 different observables***
- ***They are described by different bi-linear combination of amplitudes***
- ***Fit of all observables combined offers rigorous constraints on reaction amplitude at real energy axis***

2-Body Photoproduction off Protons: Data and Analysis Approaches

✓ - *data acquired* ✔ - *analyzed/published*

Observable	σ	Σ	T	P	E	F	G	H	T_x	T_z	L_x	L_z	O_x	O_z	C_x	C_z
$p\pi^0$	✔	✔	✓		✓	✓	✓	✓								
$n\pi^+$	✔	✔	✓		✔	✓	✓	✓								
$p\eta$	✔	✓	✓		✔	✓	✓	✓								
$p\eta'$	✔	✓	✓		✓	✓	✓	✓								
$K^+\Lambda$	✔	✔	✔	✔	✓	✓	✓	✓	✓	✓	✓	✓	✔	✔	✔	✔
$K^+\Sigma^0$	✔	✔	✔	✔	✓	✓	✓	✓	✓	✓	✓	✓	✔	✔	✔	✔
$K^{+*}\Lambda$	✔			✔					SDME							
$K^{0*}\Sigma^+$	✔	✓									✓	✓	SDME			

γp→X

Coupled-channel approaches for N* parameters extraction from exclusive meson photoproduction off protons data

Bonn-Gatchina A.V. Anisovich et al., Eur. Phys. J. A53, 242 (2017).
A.V. Anisovich et al., Eur. Phys. J. A50, 129 (2014).
A.V. Anisovich et al., Eur. Phys. J. A48, 15 (2012).

Argonne-Osaka H. Kamano et al., Phys. Rev. C94, 015201 (2016).
H. Kamano et al., Phys. Rev. C88, 035209 (2013).

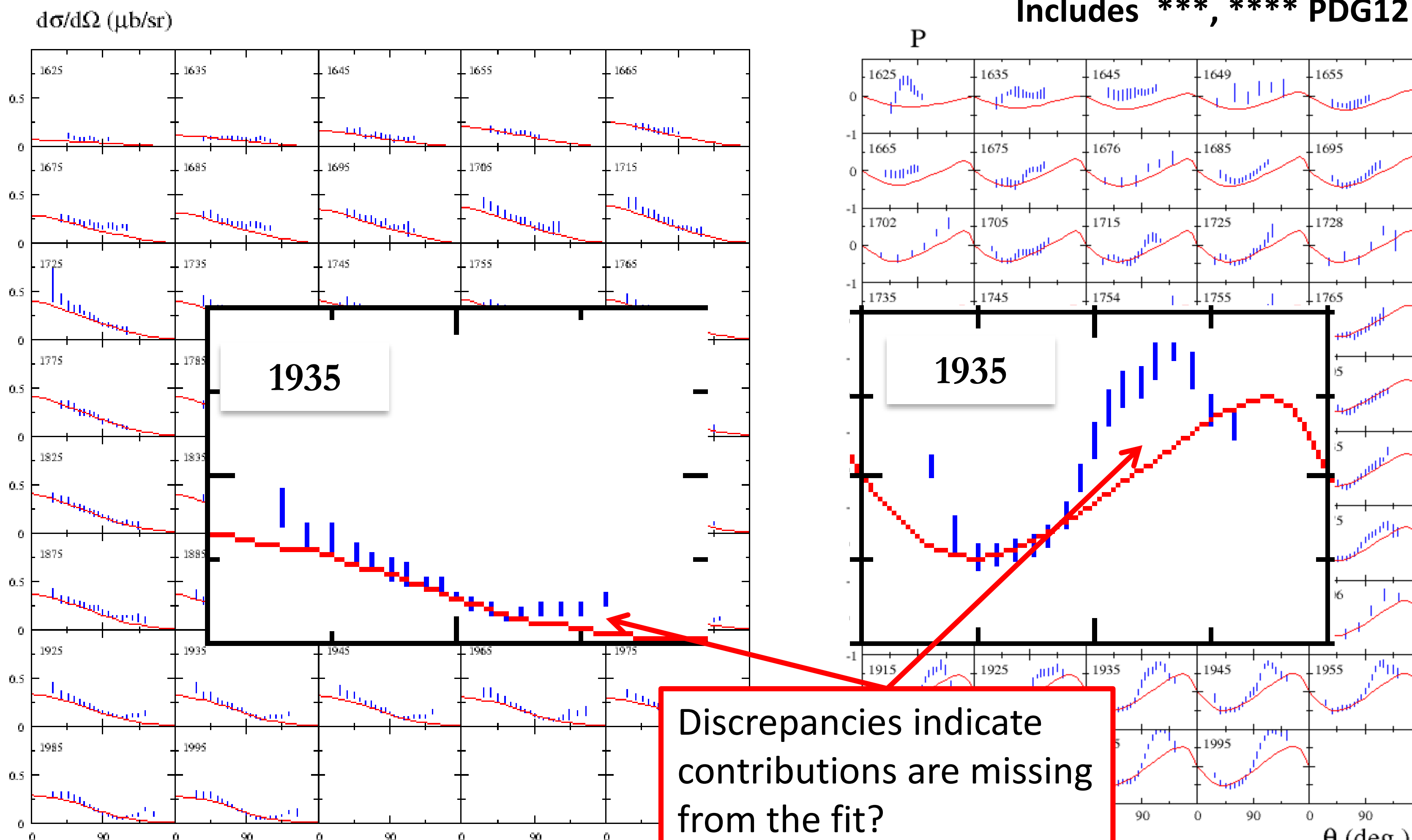
GWU-Julich D. Rönchen et al., Eur. Phys. J. A51, 70 (2015).
D. Rönchen et al., Eur. Phys. J. A50, 101 (2014).

Establishing the N* spectrum

Hyperon photoproduction $\gamma p \rightarrow K^+\Lambda \rightarrow K^+ p \pi^-$

ANL-Osaka 8 coupled-channel analysis

Includes *, **** PDG12 states**



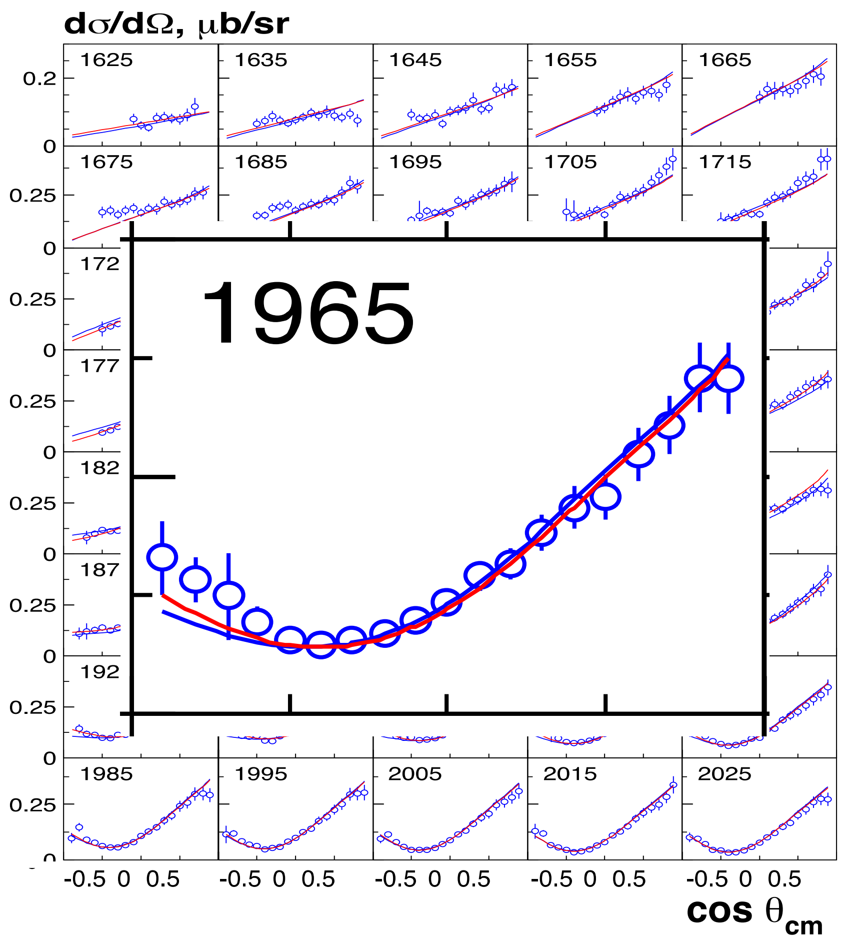
PDG(2010) states insufficient to fit KΛ data

Shows the importance of polarization data

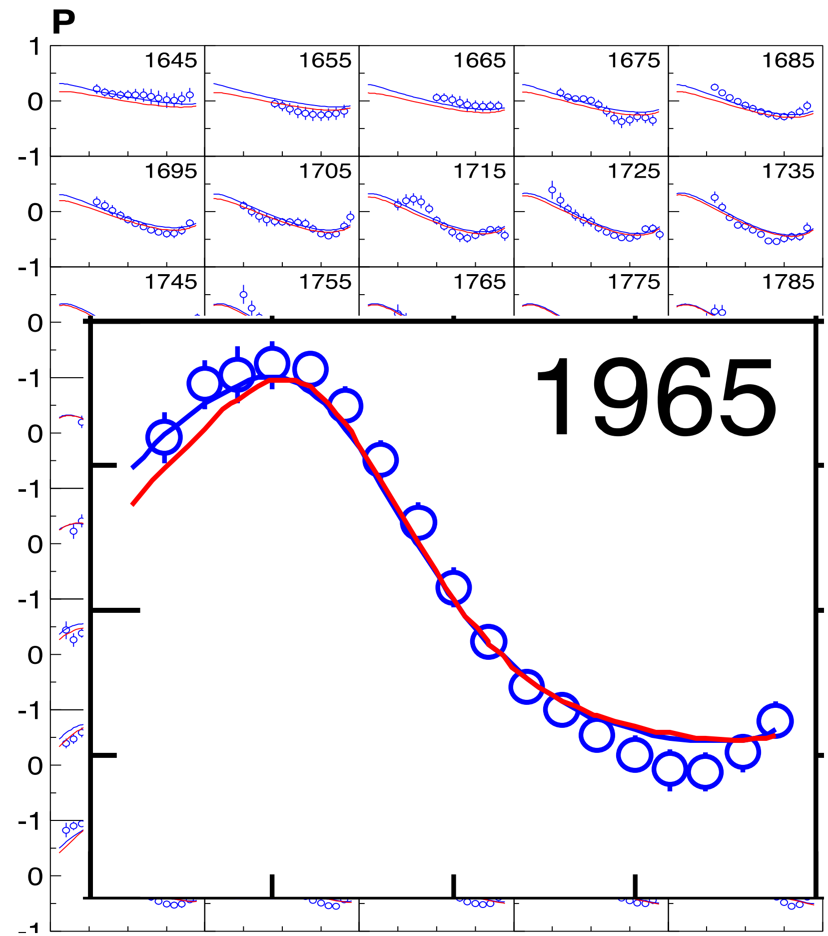
Establishing the N* spectrum, cont'd

Hyperon photoproduction $\gamma p \rightarrow K^+\Lambda \rightarrow K^+ p \pi^-$

Bonn-Gatchina multichannel analysis:
9 new resonances were included



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

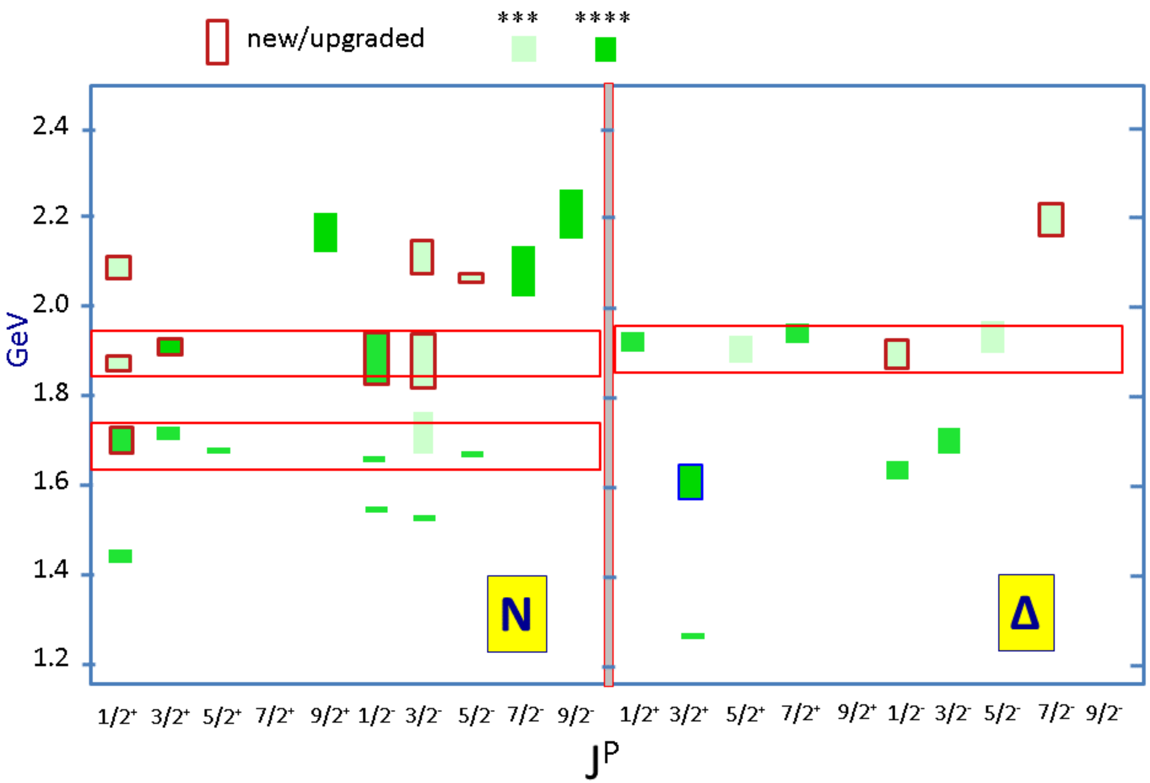


A.V. Anisovich et al, EPJ A48, 15 (2012)

Advances in Exploration of the N*-Spectrum

Several new nucleon resonances were established in a global multi-channel analysis of exclusive photoproduction data

N^*/Δ^* Spectrum 2018

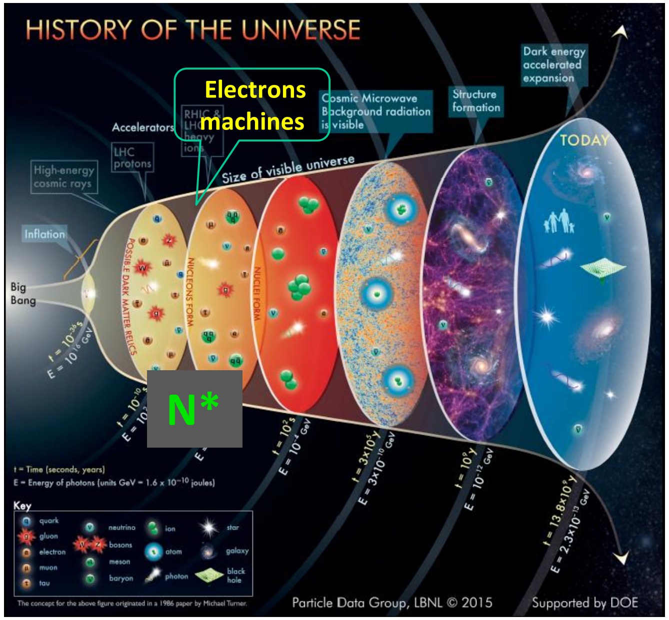


Nucleon resonances listed in Particle Data Group (PDG) tables

State N(mass)J^P	PDG pre 2012	PDG 2018*
N(1710)$1/2^+$	***	****
N(1880)$1/2^+$		***
N(1895)$1/2^-$		****
N(1900)$3/2^+$	**	****
N(1875)$3/2^-$		***
N(2100)$1/2^+$	*	***
N(2120)$3/2^-$		***
N(2000)$5/2^+$	*	**
N(2060)$5/2^-$		***
Δ(1600)$3/2^+$	***	****
Δ(1900)$1/2^-$	**	***
Δ(2200)$7/2^-$	*	***

Pave the way for the search for nucleon gluonic excitations with CLAS12

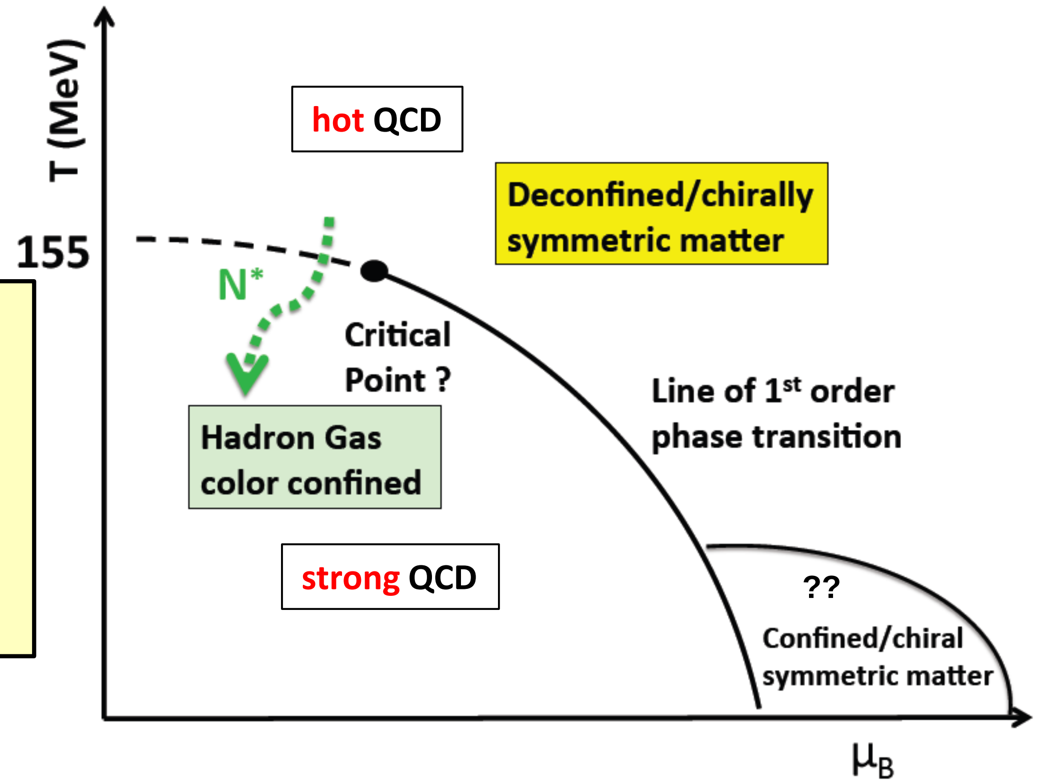
Nucleon Resonances in the History of the Universe



Dramatic events occur in the micro-second old universe during the transition from the QGP phase to hadron phase.

- Chiral symmetry is broken
- Quarks acquire mass
- Baryon resonances occur
- Quark-gluon confinement emerges

Full baryon spectrum shaped this transition



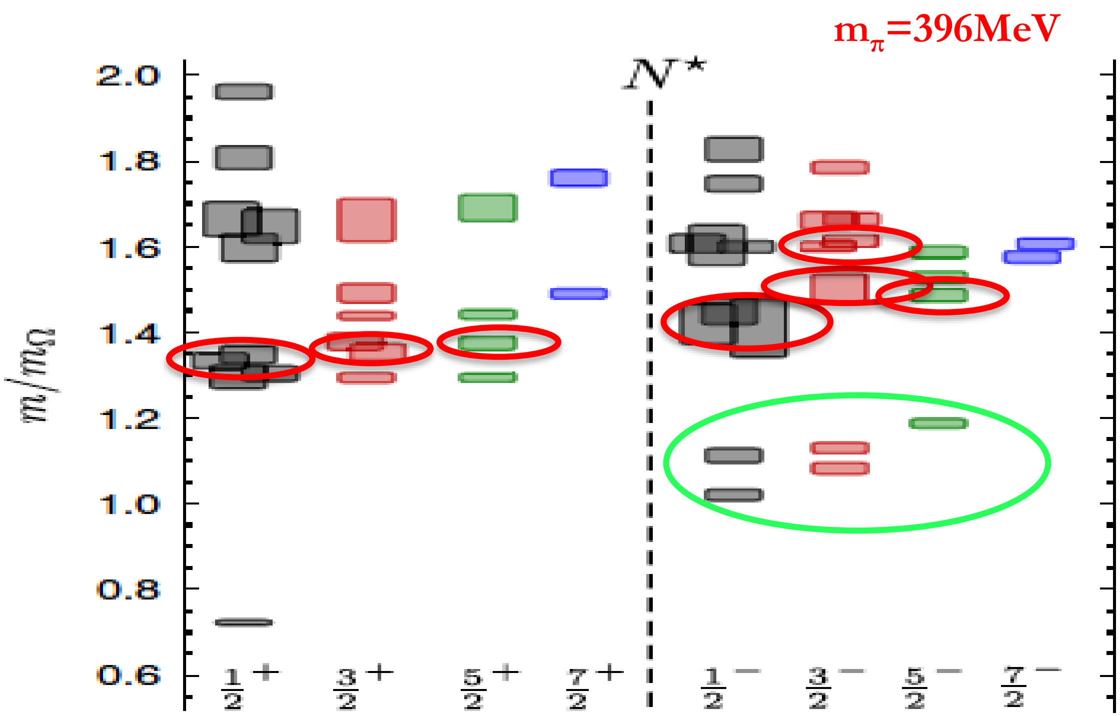
Towards Description of the N* Spectrum from the First Principles of QCD

R. Edwards et al., Phys. Rev. D84 (2011) 074508

Ignoring the mass scale, new states fit with the J^P values predicted from LQCD

m_Ω = 1672 MeV

Fit needed
N(1860)5/2$^+$
N(1900)3/2$^+$
N(1880)1/2$^+$



Fit needed
N(2060)5/2$^-$
N(2120)3/2$^-$
N(1875)3/2$^-$
N(1895)1/2$^-$

N(1675)5/2$^-$
N(1700)3/2$^-$
N(1520)3/2$^-$
N(1650)1/2$^-$
N(1535)1/2$^-$

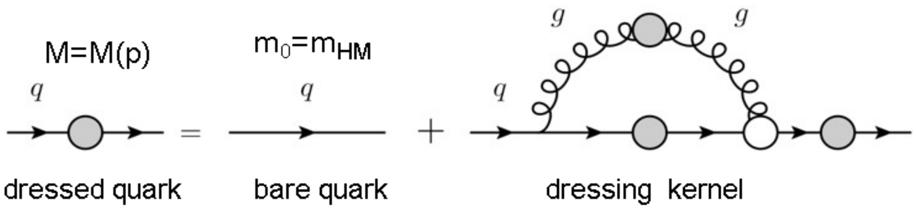
Lowest J^+ states 500 -700 MeV high

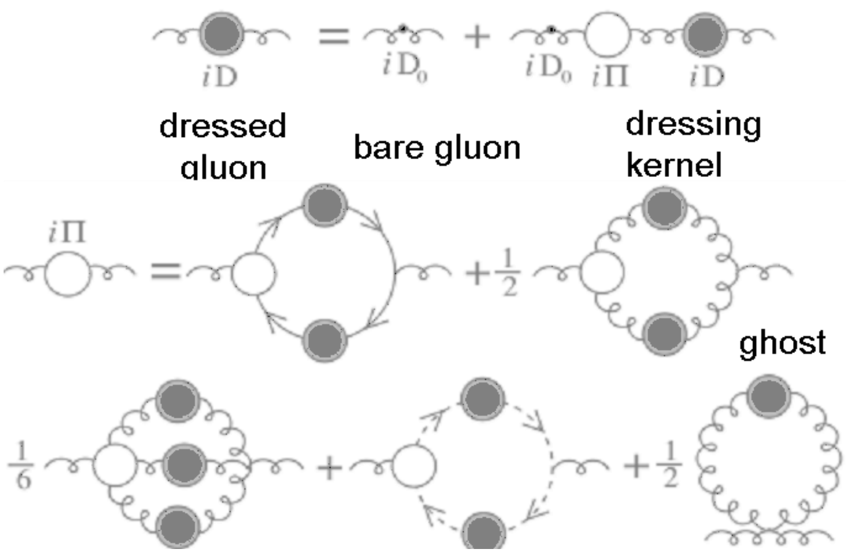
Lowest J^- states 200-300 MeV high

- **Observation of ``missing" resonances both in photo- and electroproduction data with Q^2-independent masses and hadronic decay width will prove the state existence.**
- **Foster the development of approaches for understanding of the resonance spectrum emergence from QCD.**

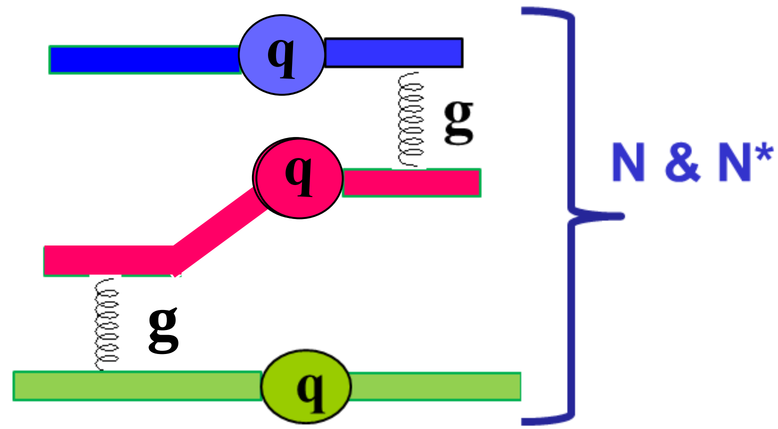
Excited Nucleon States and Insight into Strong QCD Dynamics

Emergence of Dressed Quarks and Gluons
D. Binosi, et al, Phys. Rev. D95, 031501 (2017)

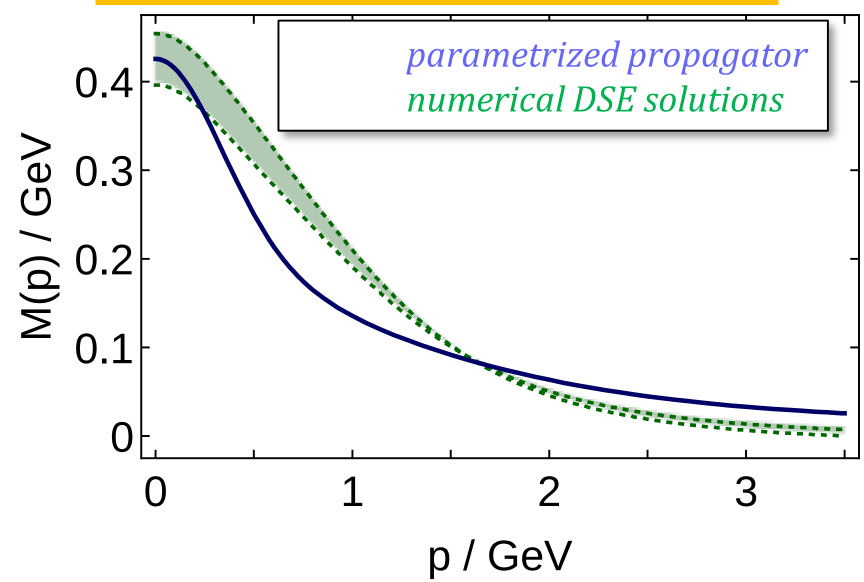




Dressed Quark Borromeo Binding in Baryons
Ch. Chen, et al, Phys. Rev. D97, 034016 (2018)



Dressed Quark Mass Function
C.D. Roberts, Few Body Syst. 58, 5 (2017)



Inferred from QCD Lagrangian with the only Λ_{QCD} parameter

N* structure studies address:

- **Nature of > 98% of hadron mass**
- **Confinement and color charge emergence from QCD**
- **Full complexity of qq-interaction and 3-dressed-quark Faddeev kernels**

Summary of Published CLAS Data on Exclusive Meson Electroproduction off Protons in N* Excitation Region

Hadronic final state	Covered W-range, GeV	Covered Q^2-range, GeV^2	Measured observables
$\pi^+ n$	**1.1-1.38** **1.1-1.55** **1.1-1.7** **1.6-2.0**	**0.16-0.36** **0.3-0.6** **1.7-4.5** **1.8-4.5**	**$d\sigma/d\Omega$** **$d\sigma/d\Omega$** **$d\sigma/d\Omega$, A_b** **$d\sigma/d\Omega$**
$\pi^0 p$	**1.1-1.38** **1.1-1.68** **1.1-1.39**	**0.16-0.36** **0.4-1.8** **3.0-6.0**	**$d\sigma/d\Omega$** **$d\sigma/d\Omega$, A_b,A_t,A_{bt}** **$d\sigma/d\Omega$**
ηp	**1.5-2.3**	**0.2-3.1**	**$d\sigma/d\Omega$**
$K^+\Lambda$	**thresh-2.6**	**1.40-3.90** **0.70-5.40**	**$d\sigma/d\Omega$** **P^0, P'**
$K^+\Sigma^0$	**thresh-2.6**	**1.40-3.90** **0.70-5.40**	**$d\sigma/d\Omega$** **P'**
$\pi^+\pi^- p$	**1.3-1.6** **1.4-2.1** **1.4-2.0**	**0.2-0.6** **0.5-1.5** **2.0-5.0**	**Nine 1-fold differential cross sections**

- $d\sigma/d\Omega$–CM angular distributions
- A_b,A_t,A_{bt}-longitudinal beam, target, and beam-target asymmetries
- P^0, P' –recoil and transferred polarization of strange baryon

Latest extensions

Over 120,000 data points!

Almost full coverage of the final hadron phase space

The measured observables from CLAS for the exclusive electroproduction of all listed final states are stored in the CLAS Physics Data Base http://clas.sinp.msu.ru/cgi-bin/jlab/db.cgi.

Approaches for Extraction of $\gamma_v NN^*$ Electrocouplings from the CLAS Exclusive Meson Electroproduction Data

Analyses of different meson electroproduction channels independently:

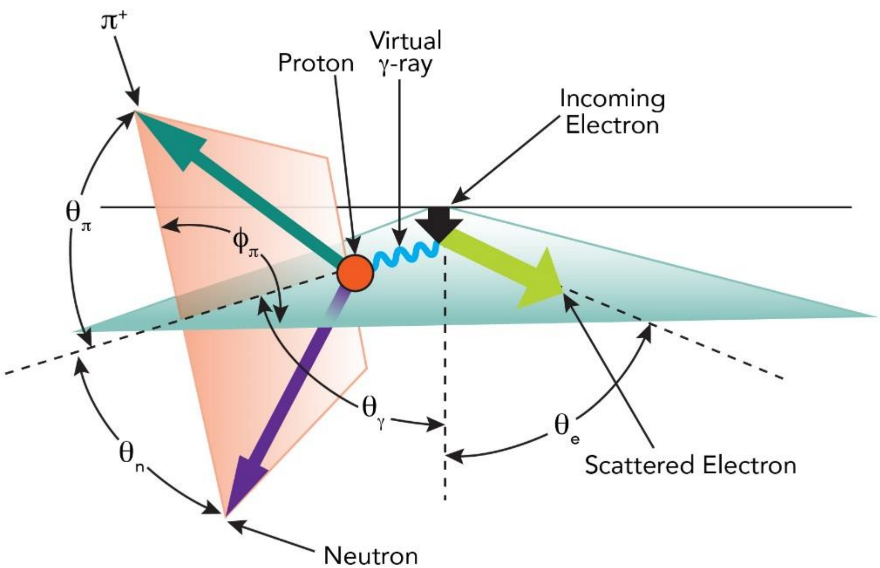
- $\pi^+ n$ and $\pi^0 p$ channels:
  Unitary Isobar Model (UIM) and Fixed-t Dispersion Relations (DR)
  I.G. Aznauryan, Phys. Rev. C67, 015209 (2003)
  I.G. Aznauryan et al. (CLAS), Phys. Rev. C80, 055203 (2009)
  I.G. Aznauryan et al. (CLAS), Phys. Rev. C91, 045203 (2015)
- ηp channel:
  Extension of UIM and DR
  I.G. Aznauryan, Phys. Rev. C68, 065204 (2003)
  Data fit at W<1.6 GeV, assuming N(1535)1/2$^-$ dominance
  H. Denizli et al. (CLAS), Phys. Rev. C76, 015204 (2007)
- $\pi^+\pi^- p$ channel:
  Data driven JLab-MSU meson-baryon model (JM)
  V.I. Mokeev, V.D. Burkert et al., Phys. Rev. C80, 045212 (2009)
  V.I. Mokeev et al. (CLAS), Phys. Rev. C86, 035203 (2012)
  V.I. Mokeev, V.D. Burkert et al., Phys. Rev. C93, 054016 (2016)

Global coupled-channel analysis of $\gamma_{r,v}N$, πN, ηN, $\pi\pi N$, $K\Lambda$, $K\Sigma$ exclusive channels:

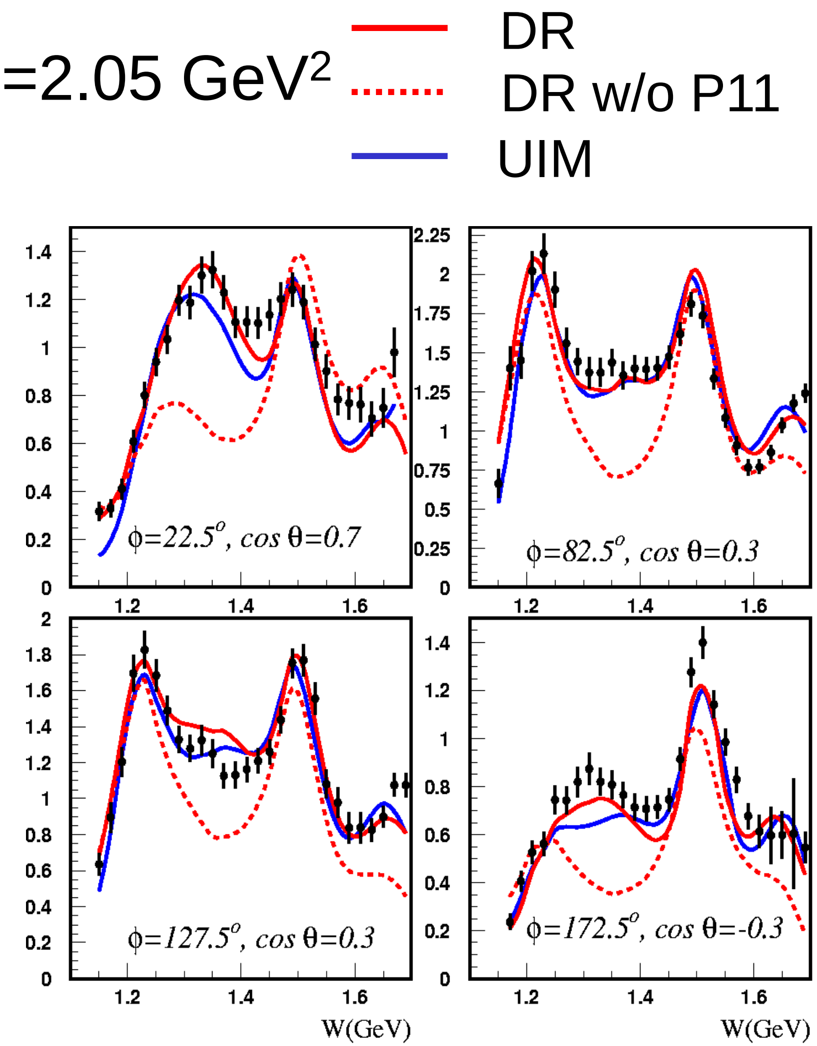
H. Kamano, Few Body Syst. 59, 24 (2018)
H. Kamano, JPS Conf. Proc. 13, 010012 (2017)

Accessing Resonance Electrocouplings from the π^+n Differential Electroproduction off Protons Cross Sections

Kinematics of exclusive π^+n electroproduction off protons (Lab. frame)



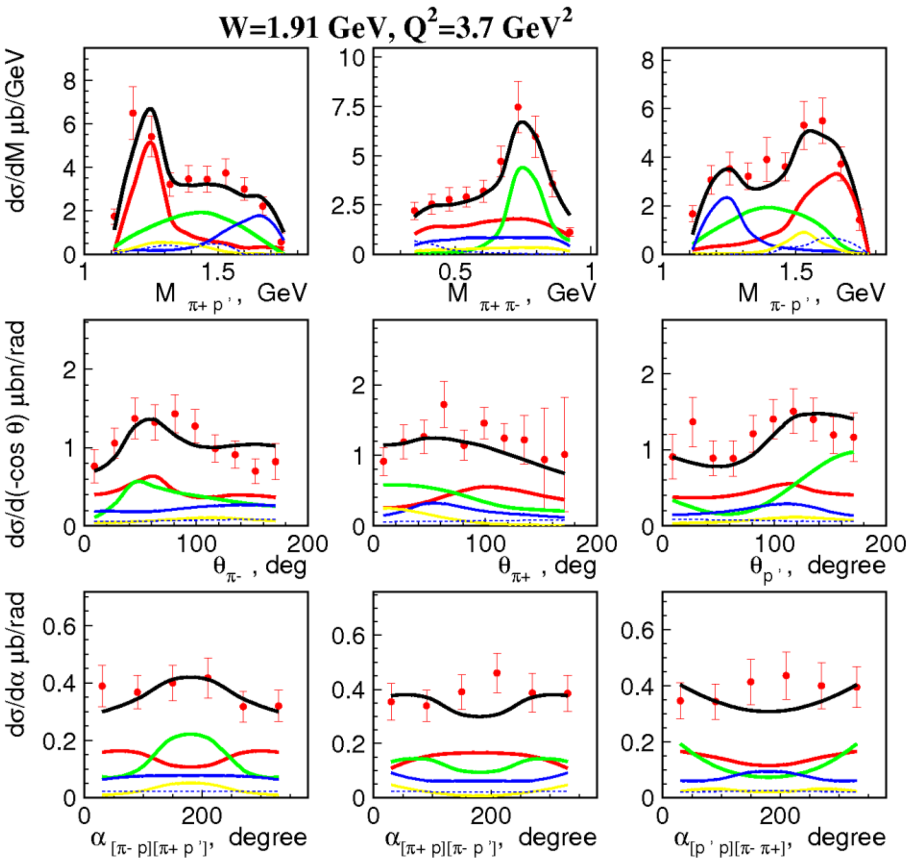
Q^2=2.05 GeV^2



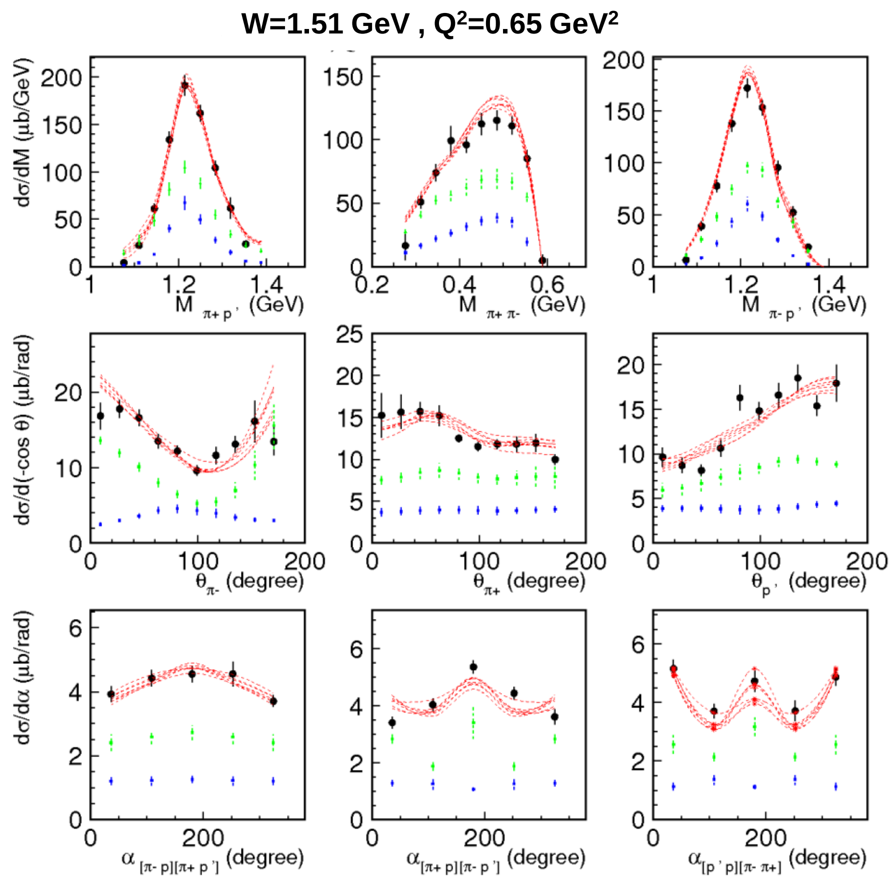
The final pion angles are in the CM-frame of the final hadrons

Accessing Resonance Electrocouplings from the $\pi^+\pi^-p$ Differential Electroproduction off Protons Cross Sections

Contributing mechanisms seen in the data



Resonant and non-resonant contributions



full JM — ρp — π^+ N(1520)3/2$^-$

$\pi^-\Delta^{++}$ — $\pi^+\Delta^0$ — π^+ N(1680)5/2$^+$

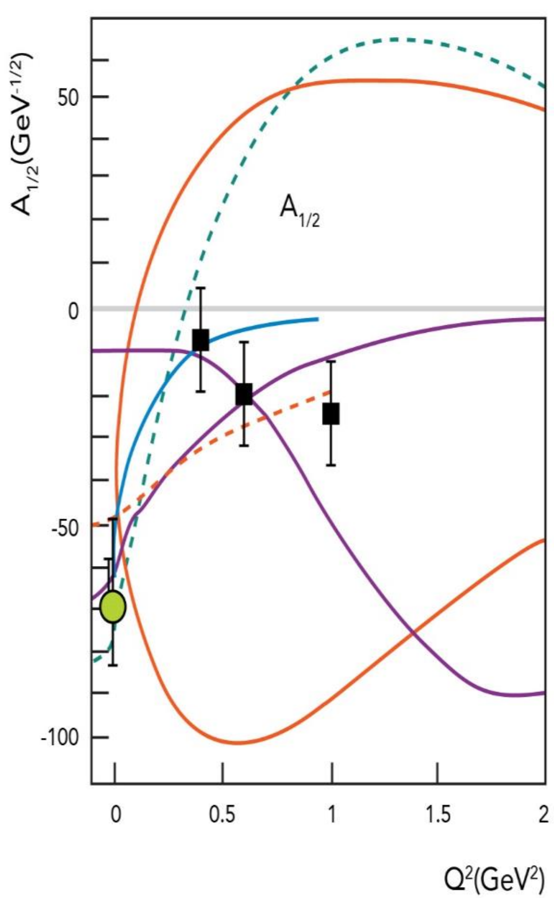
data fit within JM under variations of both resonant and background parameters

background cross sections

resonant cross sections

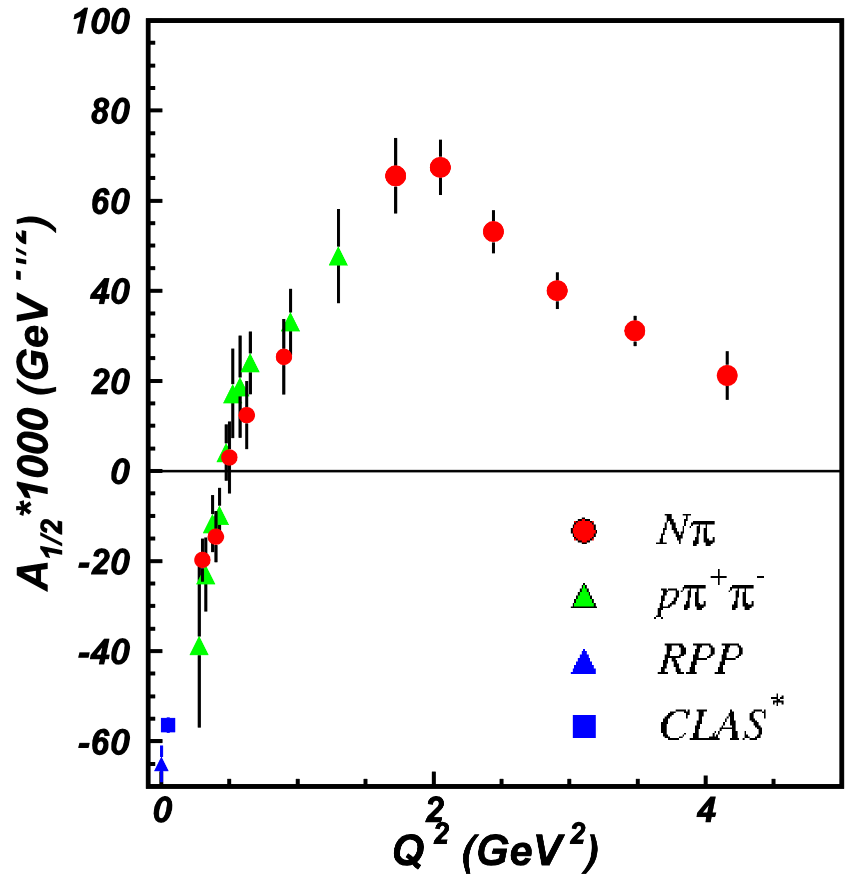
Roper Resonance in 2002 & 2018

2002



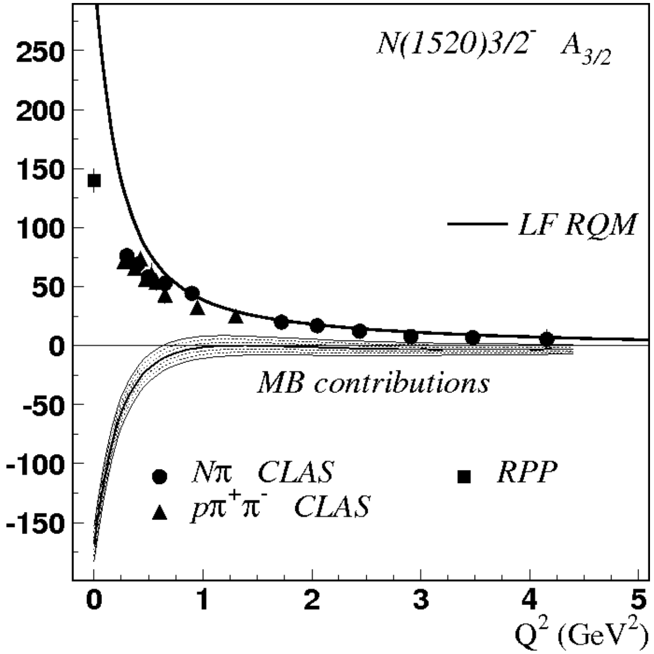
V. Burkert, Baryons 2002

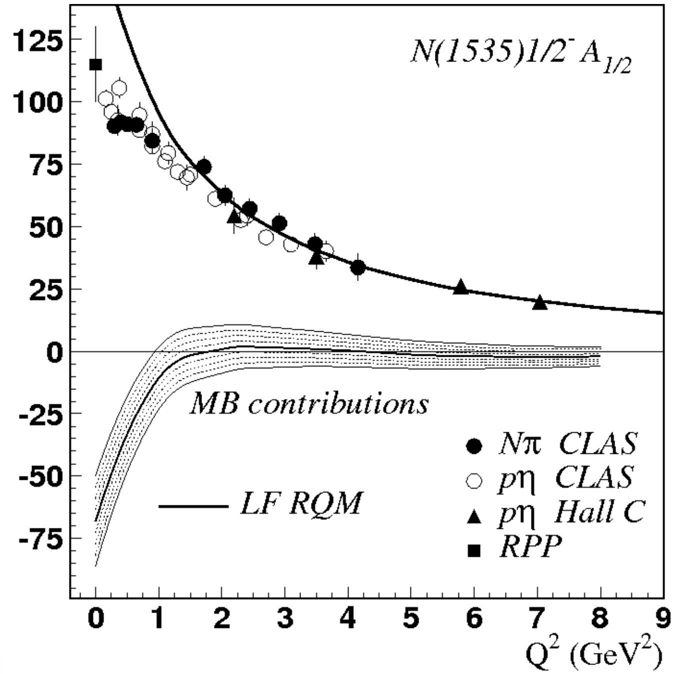
2018



V. D. Burkert, Baryons 2016

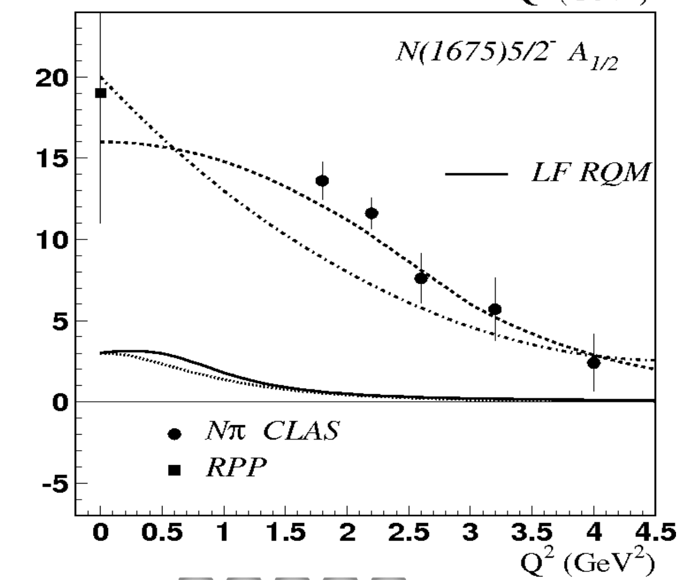
$\gamma_v pN^*$ Electrocouplings from $N\pi$, $N\eta$, and $\pi^+\pi^-p$ Electroproduction





CLAS data points from:
I.G. Aznauryan et al., Phys. Rev. C80, 055203 (2009).
K. Park et al., Phys. Rev. C91, 045203 (2015).
V.I. Mokeev et al., Phys. Rev . C86, 035203 (2012).
V.I. Mokeev et al., Phys. Rev.. C93, 025206 (2016).

LF RQM:
I.G. Aznauryan and V.D. Burkert, Phys. Rev. C95, 065207 (2017).



Consistent values of resonance electrocouplings from analyses of $N\pi$, $N\eta$, and $\pi^+\pi^-p$ electroproduction strongly support their reliable extraction

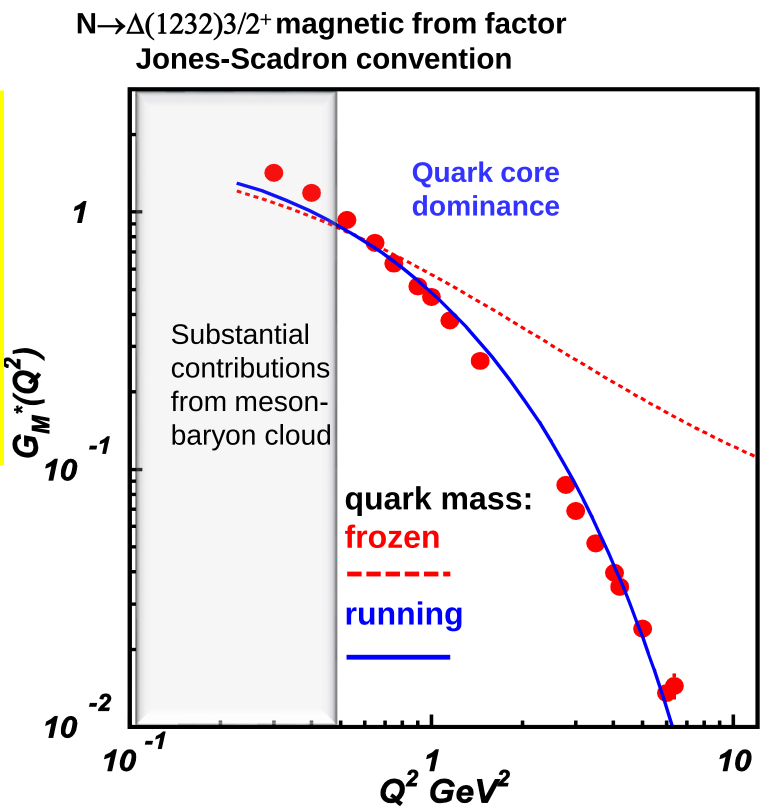
The structure of all resonances studied with CLAS represents a complex interplay between inner quark core and external meson-baryon cloud.

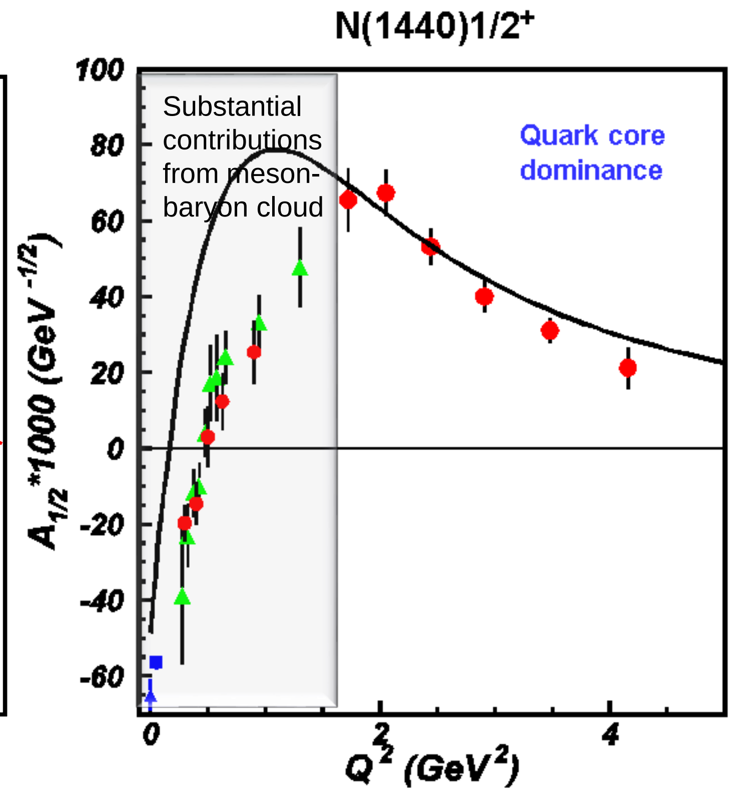
In near term CLAS will provide electrocouplings of most resonances in the mass range W<2.0 GeV at Q^2<5.0 GeV^2

From Resonance Electrocouplings to Hadron Mass Generation

<u>Dyson-Schwinger Equations (DSE):</u>

- **J. Segovia et al., Phys .Rev. Lett. 115, 171801 (2015).**
- **J. Segovia et al., Few Body Syst. 55, 1185 (2014).**



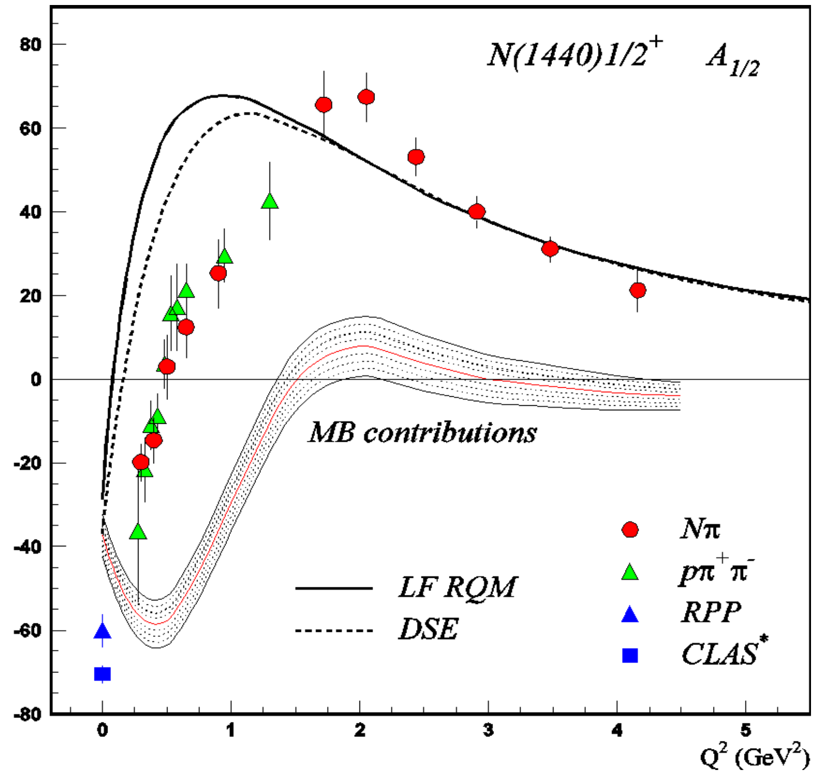


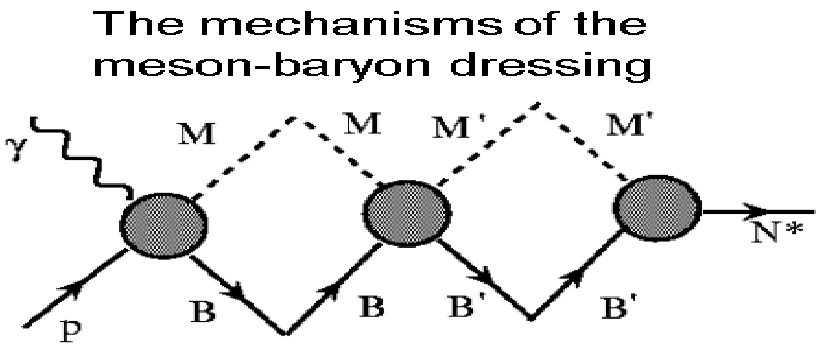
DSE analyses of the CLAS data on Δ(1232)3/2+ electroexcitation demonstrated that dressed quark mass is running with momentum.

Good data description at the distances where quark core dominates (Q^2>2.0 GeV^2) achieved with <u>the same dressed quark mass function</u> for the ground and excited nucleon states of distinctively different structure validate the DSE results on momentum dependence of dressed quark mass. $\gamma_v pN^*$ electrocoupling data offer access to the strong QCD dynamics behind hadron mass generation.

One of the most important achievements in hadron physics of the last decade in synergistic efforts between experimentalists and theorists.

Resolving Roper Puzzle





CLAS data in the range of Q^2<5.0 GeV^2 revealed the structure of $N(1440)1/2^+$ as a complex interplay between inner core of three dressed quarks in the first radial excitation and external meson-baron (MB) cloud

LF RQM-Light Front relativistic quark model: V.D. Burkert, I.G. Aznauryan, Phys . Rev. C85, 055202 (2012); Phys. Rev. C95, 065207 (2017).

Quark core description within LF RQM and DSE is consistent

For more details on resolving Roper puzzle see:
V. D. Burkert and C.D. Roberts ``Roper resonance-solution to the fifty year puzzle", arXiv:1710.02549 [nucl-ex] .

CLAS12 N* Program at High Q^2

E12-09-003

Nucleon Resonance Studies with CLAS12

Gothe, Mokeev, Burkert, Cole, Joo, Stoler

E12-06-108A

KY Electroproduction with CLAS12

Carman, Gothe, Mokeev

- Measure exclusive electroproduction cross sections from an unpolarized proton target with polarized electron beam for $N\pi$, $N\eta$, $N\pi\pi$, KY:

  E_b = 11 GeV, Q^2 = 3 → 12 GeV^2, W → 3.0 GeV with nearly complete coverage of the final state phase space

- Key Motivation

  Study the structure of all prominent N states in the mass range up to 2.0 GeV vs. Q^2 up to 12 GeV^2.*

  CLAS12 is the only facility to map-out the N quark with minimal meson-baryon cloud contributions.*

The experiments already started in February 2018!

Emergence of Hadron Mass and Quark-Gluon Confinement

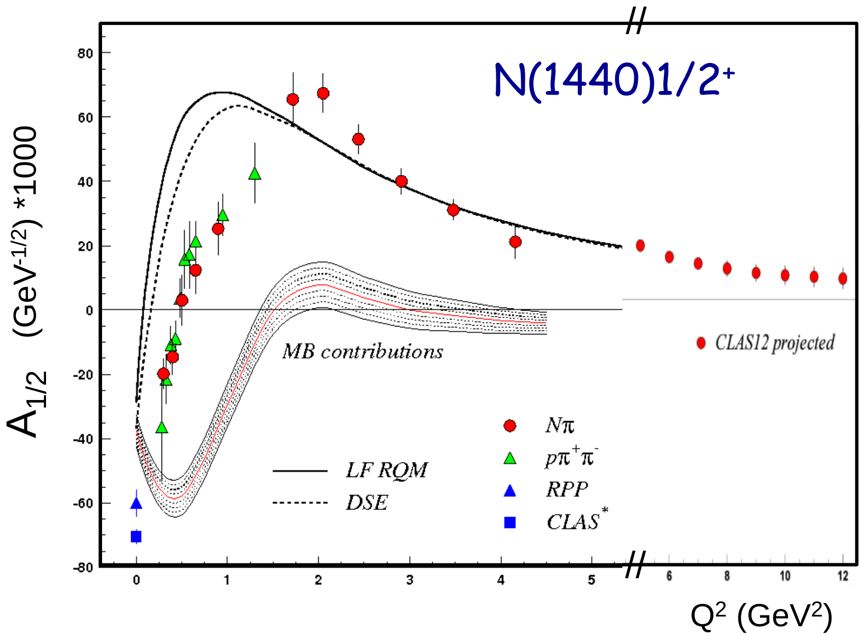
N* electroexcitation studies at JLab will address the critical open questions:

How is >98% of visible mass generated?

How does confinement emerge from QCD and how is it related to Dynamical Chiral Symmetry Breaking?

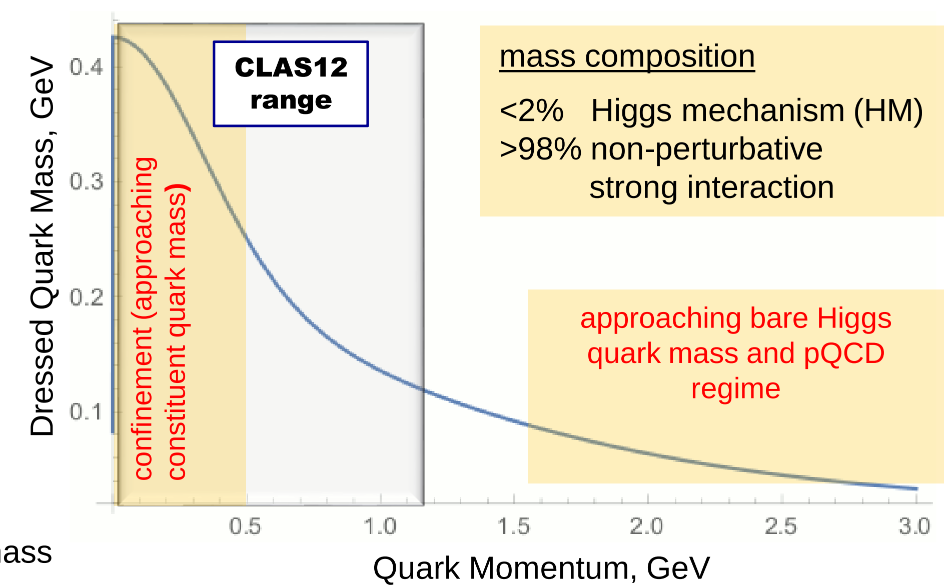
What is the behavior of QCD's running coupling at infrared momenta?

Mapping-out quark mass function from the CLAS12 results on $\gamma_v pN^*$ electrocouplings of spin-isospin flip, radial, and orbital excited nucleon resonances at $5<Q^2<12$ GeV^2 will allow us to explore the transition from strong QCD to pQCD regimes.



CLAS results versus theory expectations with running quark mass

Access to the dressed quark/hadron mass generation



Conclusions and Outlook

- **Global multi-channel analysis of the exclusive photo- and hadroproduction data revealed firm evidence for the existence of new N(1895)1/2$^-$, N(1900)3/2$^+$ and the elevated to the four-star status Δ(1600)3/2$^+$, N(1710)1/2$^+$ resonances with a major impact from the CLAS KΛ, KΣ photoproduction data and improve considerably knowledge on the spectrum of high-lying resonances.**

- **High quality meson electroproduction data from CLAS have allowed us to determine the electrocouplings of most well-established resonances in the mass range up to 1.8 GeV from analyses of π^+n, π^0p, ηp, and $\pi^+\pi^-$p electroproduction channels.**

- **<u>Profound impact on the exploration of strong QCD dynamics:</u>**
  a) first DSE evaluations of Δ(1232)3/2$^+$ and N(1440)1/2$^+$ electroexcitation amplitudes with a traceable connection to the QCD Lagrangian;
  b) synergistic efforts between the experimental studies of γ_vpN* electrpocouplings in Hall B at JLab and the continuous QCD theory have revealed the capability for reliable access to the mechanisms underlying the quark/hadron mass generation.

- **Electrocouplings of most resonances in the mass range up to 2.0 GeV will become available at Q^2<5.0 GeV^2 from independent analyses of the new CLAS data on Nπ and $\pi^+\pi^-$p electroproduction in the near term future allowing us to explore the transition to the quark core dominance and confirm existence of new baryon states seen in the exclusive photoproduction**

Conclusions and Outlook

- **CLAS12 is the only available facility capable to study electrocouplings of all prominent N* states at still unexplored ranges of low photon virtualities down to 0.05 GeV^2 and highest photon virtualities for exclusive reactions from 5.0 GeV^2 to 12 GeV^2 from measurements of exclusive Nπ, $\pi^+\pi^-$p, and KY electroproduction.**

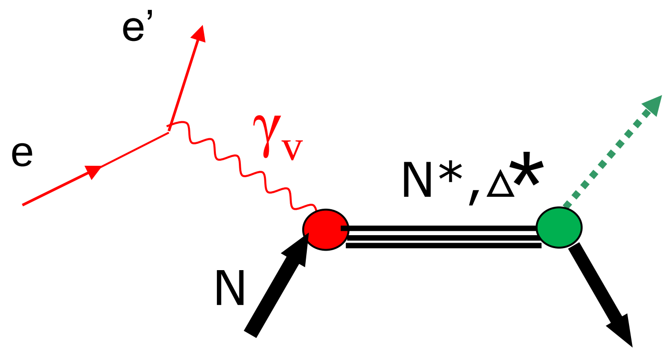
- **The expected results will allow us:**
  a) to search for hybrid-baryons and other new states of baryon matter;
  b) to map out the dressed quark mass function at the distance scales where the transition from quark-gluon confinement to pQCD regime is expected, addressing the most challenging problems of the Standard Model on the nature of >98% of hadron mass and of quark-gluon confinement.

- **Success of the N* Program will be very beneficial for the hadron physics community. It requires close collaborative efforts between *experiment and phenomenology* for resonance parameter extraction from the data, and *the QCD-based hadron structure theory* capable of relating resonance parameters to strong QCD dynamics.**

Back up

Extraction of $\gamma_v NN^*$ Electrocouplings from Exclusive Meson Electroproduction off Nucleons

Resonant amplitudes | **Non-resonant amplitudes**



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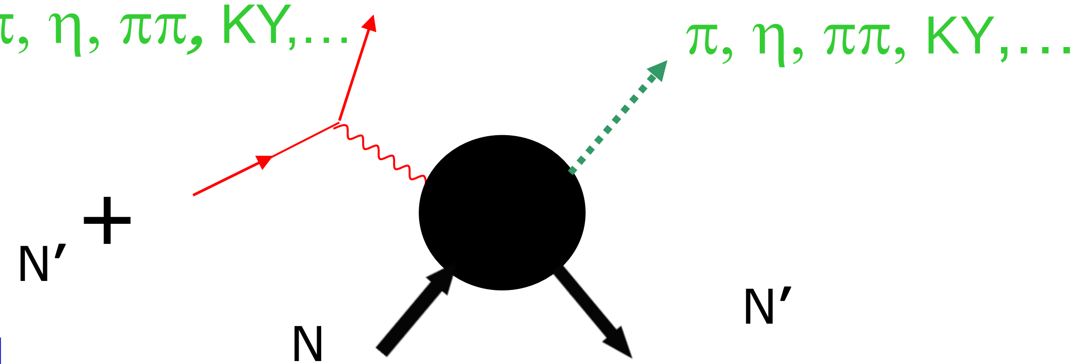


- •**Real $A_{1/2}(Q^2)$, $A_{3/2}(Q^2)$, $S_{1/2}(Q^2)$**
  or
- •**$G_1(Q^2)$, $G_2(Q^2)$, $G_3(Q^2)$**
  or
- •**$G_M(Q^2)$, $G_E(Q^2)$, $G_C(Q^2)$**

I.G. Aznauryan and V.D. Burkert, Prog. Part. Nucl. Phys. 67, 1 (2012).

<u>Definition of N* photo-/electrocouplings employed in the CLAS data analyses:</u>

$$\Gamma_\gamma = \frac{k^2_{\gamma_{N^*}}}{\pi} \frac{2M_N}{(2J_r+1)M_{N^*}} \left[|A_{1/2}|^2 + |A_{3/2}|^2 \right]$$

Γ_γ: N* electromagnetic decay widths;
W=M_{N^*} on the real energy axis.

- **Consistent results on $\gamma_v NN^*$ electrocouplings from different meson electroproduction channels and different analysis approaches demonstrate reliable extraction of these quantities.**
- **Studies of exclusive meson electroproduction off protons with the CLAS detector at JLab provided the dominant part of the information on $\gamma_v pN^*$ electrocouplings.**

N* studies at 0.05 GeV^2 < Q^2 < 7.0 GeV^2 with CLAS12

Hybrid Baryons E12-16-010	Search for hybrid baryons (qqqg) focusing on 0.05 GeV^2 < Q^2 < 2.0 GeV^2 in mass range from 1.8 to 3 GeV in $K\Lambda$, $N\pi\pi$, $N\pi$ *(A. D'Angelo, et al.)*
KY Electroproduction E12-16-010A	Study N* structure for states that couple to KY through measurements of cross sections and polarization observables that will yield Q^2 evolution of electrocoupling amplitudes at Q^2<7.0 GeV^2 *(D. Carman, et al.)*

Approved by PAC44

Run Group conditions:
E_b = 6.6 GeV, 50 days
E_b = 8.8 GeV, 50 days

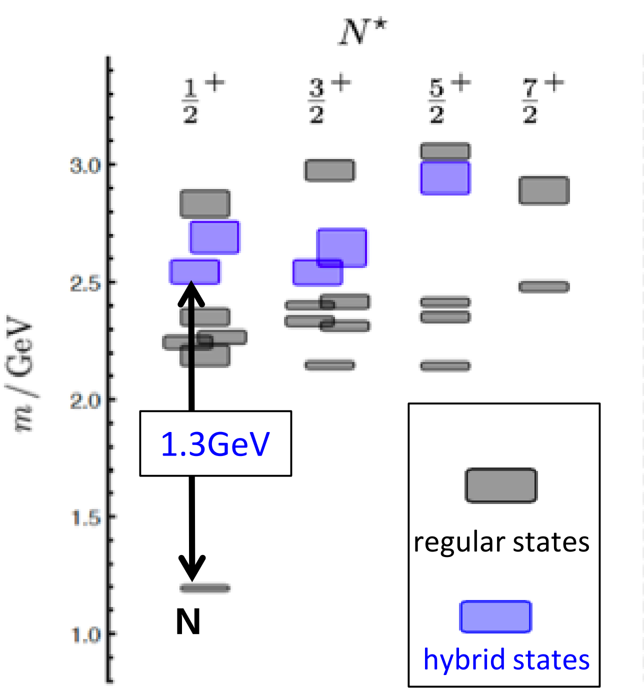
- Polarized electrons, unpolarized LH_2 target
- L = 1×10^{35} cm^{-2}s^{-1}

Hunting for Glue in Excited Baryons with CLAS12

Can glue be a structural component to generate hybrid q^3g baryon states?

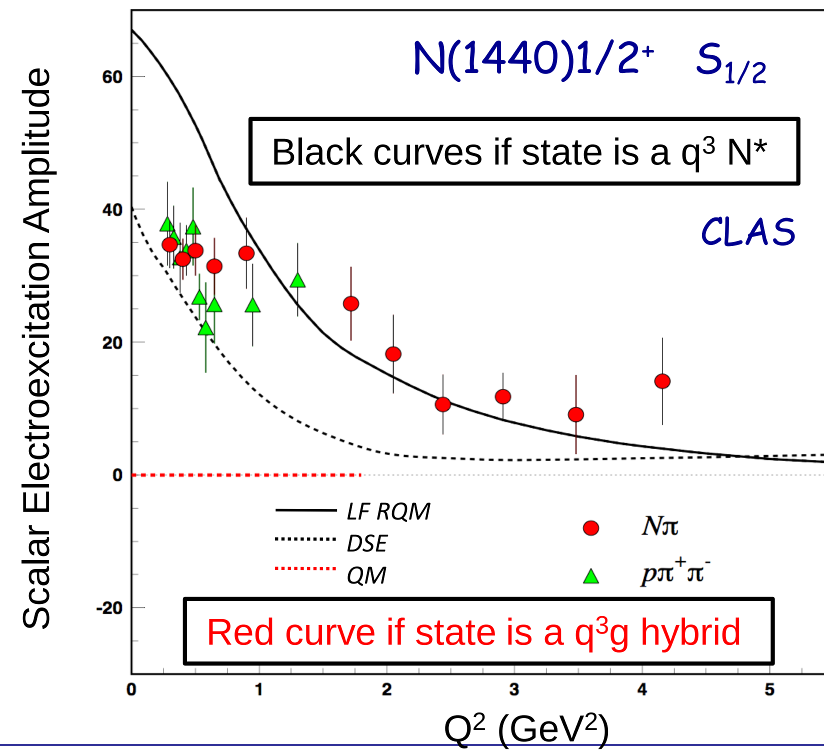
Search for hybrid baryons with CLAS12 in exclusive KY and $\pi^+\pi^-p$ electroproduction

Predictions of the N* spectrum from QCD show both regular q^3 *and* hybrid q^3g states



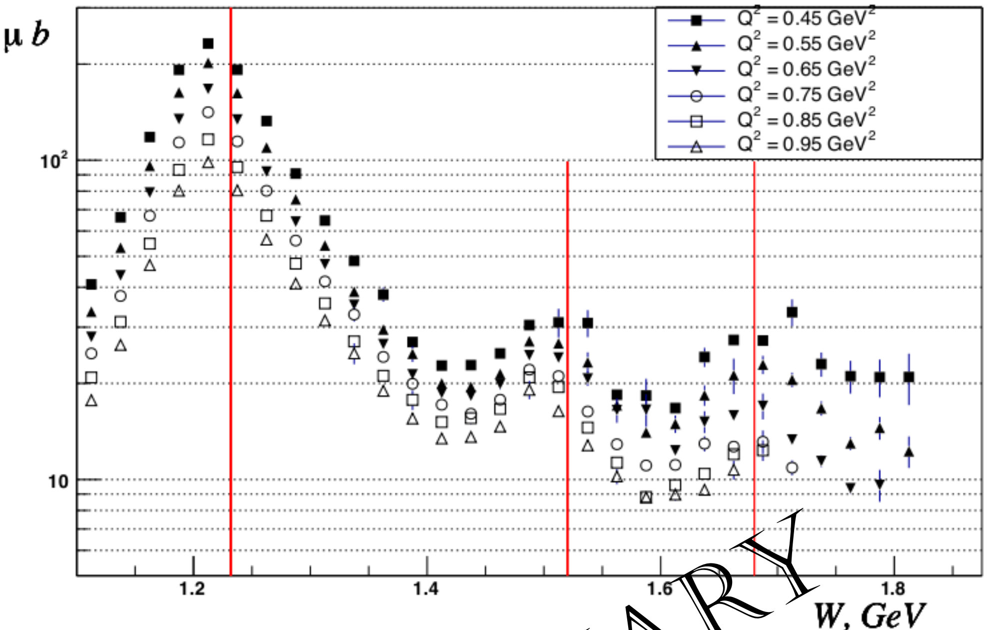
JLab LQCD group results

LQCD and/or QM predictions on Q^2 evolution of the hybrid-baryon electroexcitation amplitudes are critical in order to establish the nature of a baryon state



New CLAS Results on $\pi^0 p$ electroproduction

Fully integrated cross sections

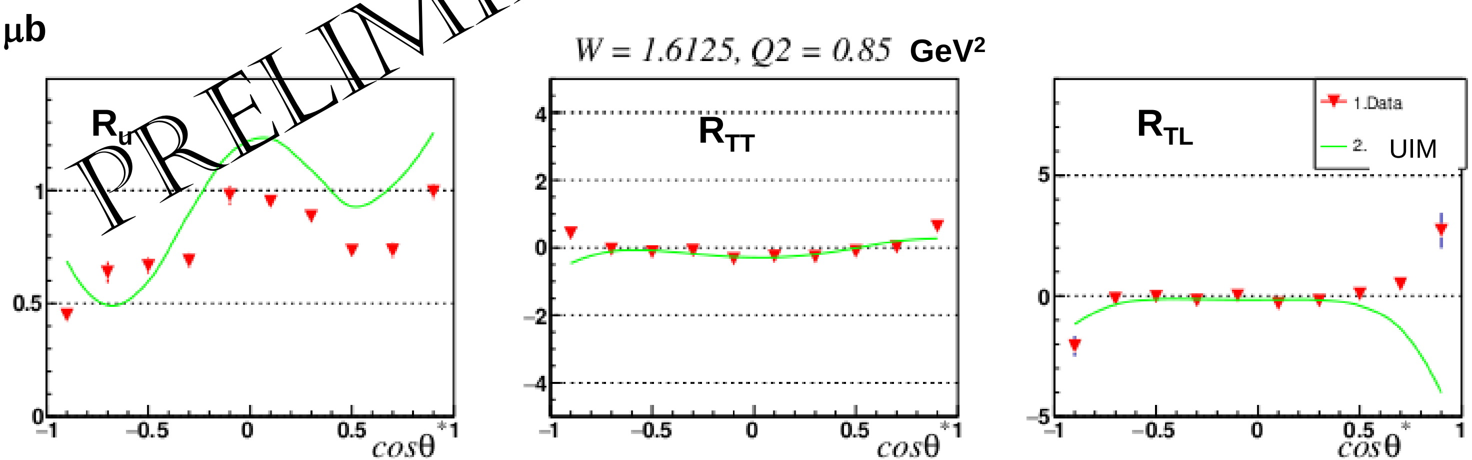


N. Markov, K.Joo, UCONN

1.10GeV<W<1.80 GeV, 0.3 GeV²<Q²<1.0 GeV²

Fit of the structure functions within the framework of UIM & DR (slides #6,7) will provide electrocouplings of the resonances in mass range up to 1.8 GeV with substantial decays to the $N\pi$ final state.

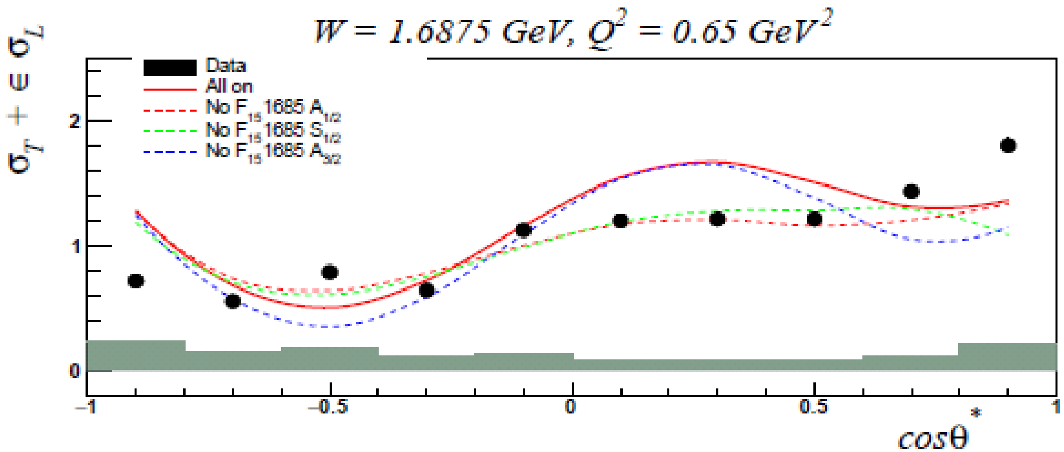
The structure functions



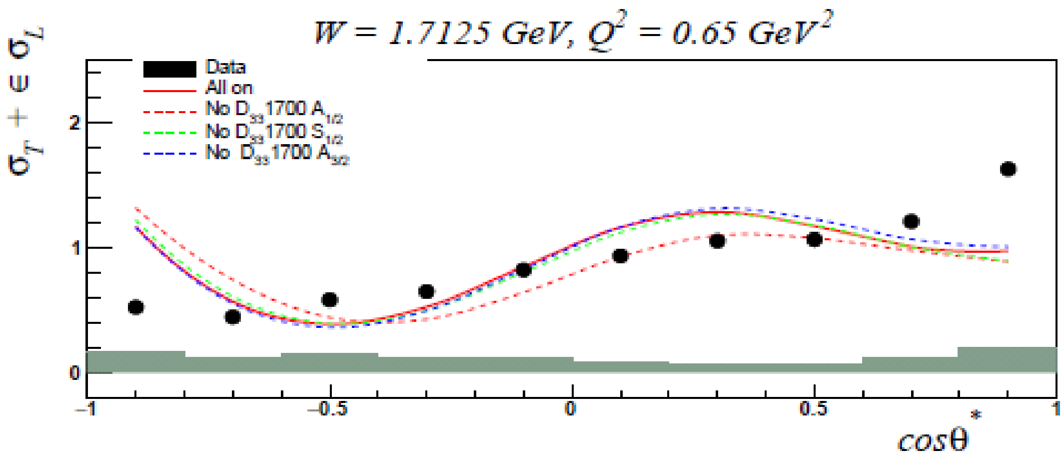
Structure of the Excited Nucleon States in the 3rd Resonance Region from $\pi^0 p$ Electroproduction off Protons

- $\gamma_v pN^*$ electrocouplings and hadronic decay widths were taken from previous analyses of the CLAS $N\pi$ and $\pi^+\pi^- p$ electroproduction off proton data.
- The data on unpolarized structure functions are compared with the UIM expectations (see slide #6) accounting for all relevant resonances and when particular $\gamma_v pN^*$ amplitudes were switched off.

N. Markov, K.Joo, UCONN



Sensitivity to electrocouplings of $N(1680)5/2^+$



Sensitivity to electrocouplings of $\Delta(1700)3/2^-$

A good prospect to obtain electrcouplings of the T=1/2, 3/2 resonances in the 3rd region with sizable decays to $N\pi$ from the CLAS $\pi^+ n$, $\pi^0 p$ electroproduction off proton data.

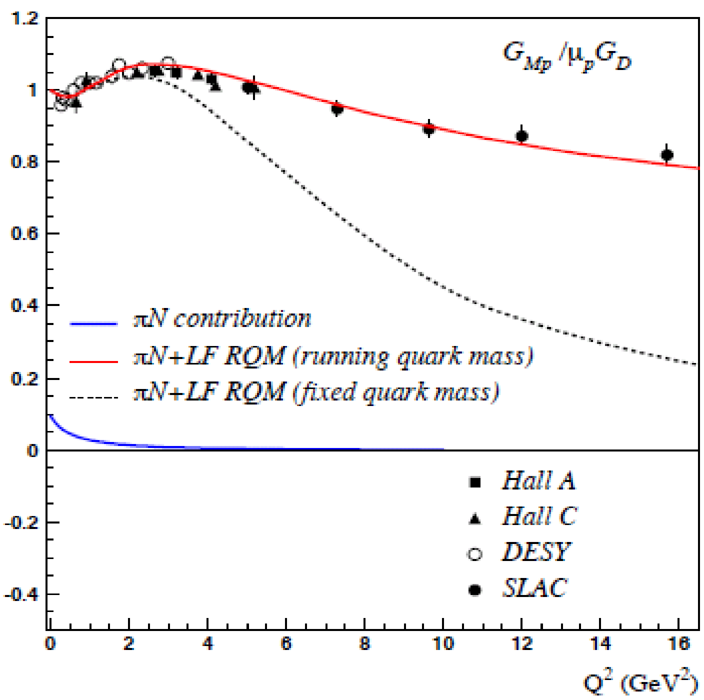
Quark Model with Input from QCD-based Approaches

Light Front QM by I.G. Aznauryan and V.D. Burkert: PRC 85, 055202 (2012).

The approach discussed here is purely phenomenological, and addresses a few topics that have some importance for the direction of the field, in particular:

- obtain a better understanding of the expected meson-baryon contributions
- study the sensitivity of the resonance transition amplitudes to the running quark mass, which is a result of the DSE approach and of LQCD calculations.

Proton Magnetic Form Factor



- Nucleon electromagnetic form factors
  $\rightarrow$ $q^3 + \pi N$ loops contributions in light-front dynamics
  $\rightarrow$ running quark mass
- Electroexcitation of $\Delta(1232)\frac{3}{2}^+$, $N(1440)\frac{1}{2}^+$, $N(1520)\frac{3}{2}^-$, and $N(1535)\frac{1}{2}^-$
  $\rightarrow$ q^3 contribution in a LF RQM with running quark mass
  $\rightarrow$ inferred MB contributions

Implementation of momentum-dependent quark mass is needed in order to reproduce elastic magnetic form factor of proton at Q^2>3.0 GeV^2