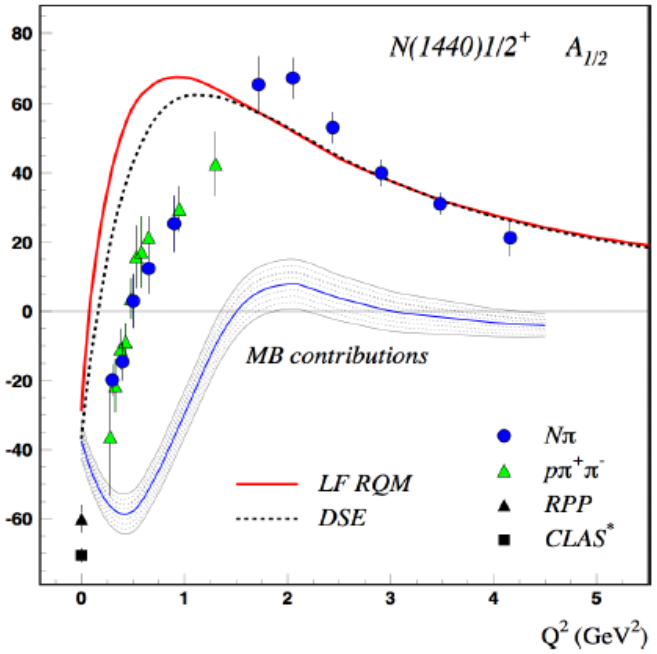
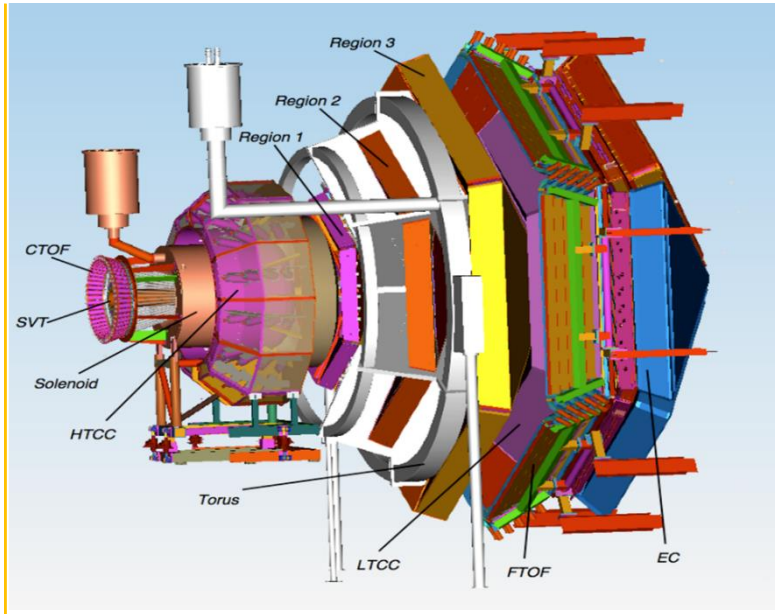
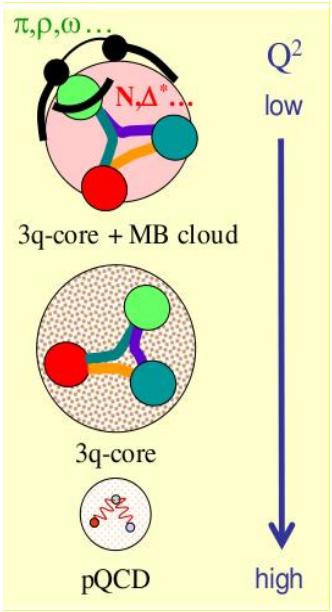
Electrocouplings with CLAS and Prospects for CLAS12

V.I. Mokeev, Jefferson Laboratory







"I am convinced that completing this chapter in the history of science will be one of the most interesting and fruitful areas of physics for at least the next thirty years"

Nathan Isgur, "Why N*'s are important", at N*2000

Hadronic Physics with Lepton and Hadron Beams
September 5 - 8, 2017
at the Jefferson Lab

Major Directions in Studies of N* Spectrum and Structure with CLAS

The experimental program on studies of the N* spectrum and structure in exclusive meson photo- and electroproduction with CLAS seeks to determine:

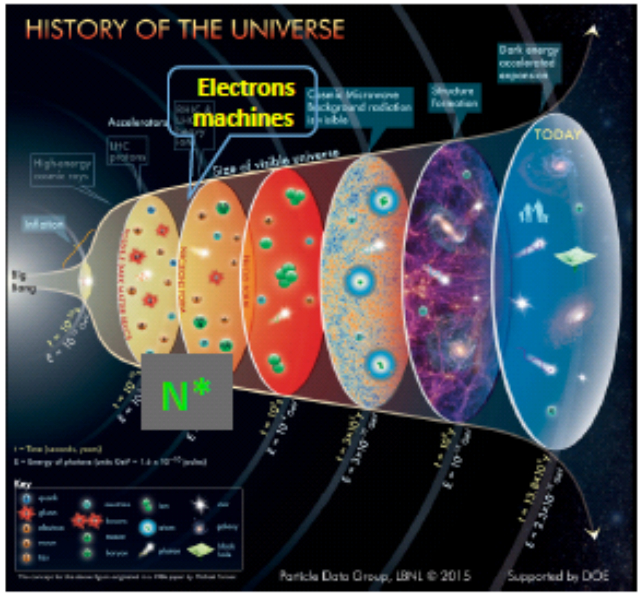
- Photo- and $\gamma_v pN^*$ electrocouplings at photon virtualities up to 5.0 GeV^2 for most of the excited proton states by analyzing all relevant meson electroproduction channels in the nucleon resonance region
- Extend knowledge of N*-spectrum and on resonance hadronic decays from the data for photo- and electroproduction reactions

A unique source of information on many facets of strong QCD in generating different excited nucleon states

Review papers:

1. I.G. Aznauryan and V.D. Burkert, Prog. Part. Nucl. Phys. 67, 1 (2012).
2. I.G. Aznauryan et al., Int. J. Mod. Phys. E22,1330015 (2013).
3. V.D. Burkert, Few Body Syst. 57, 873 (2016).
4. C.D. Roberts, J. Phys. Conf. Ser. 706, 022003 (2016).

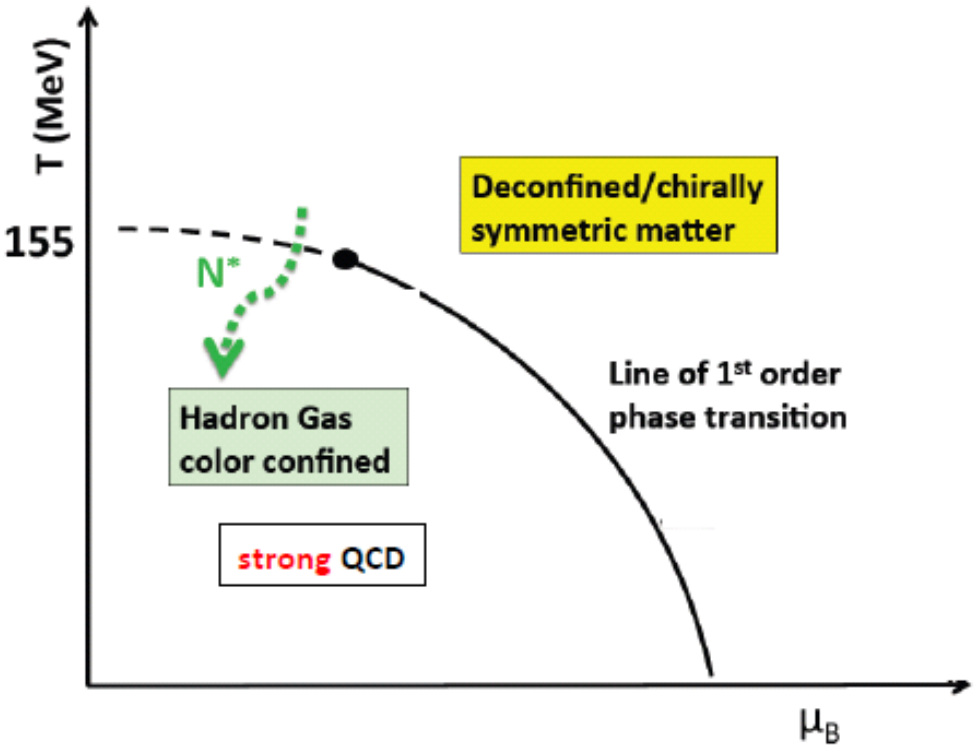
Role of N*'s in the history of the Universe



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

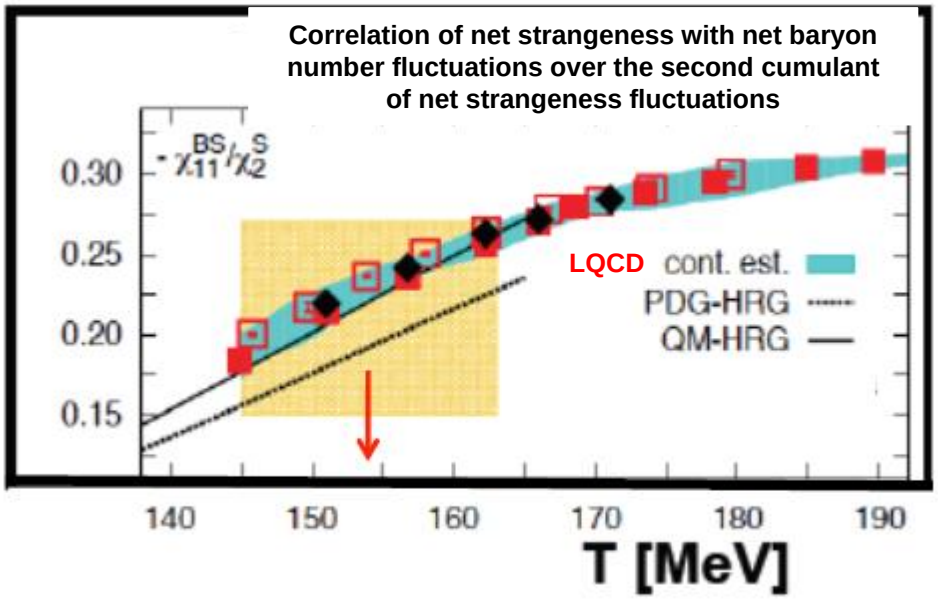
- Chiral symmetry is broken
- Quarks acquire mass
- Baryon resonances occur
- Color confinement emerges

With existing accelerators we can explore these events in isolation



Excited Nucleon States and Insight into Strong QCD Dynamics

Baryon resonance impact on early Universe evolution



A. Bazavov et al., Phys.Rev.Lett. 113 (2014) 7, 072001

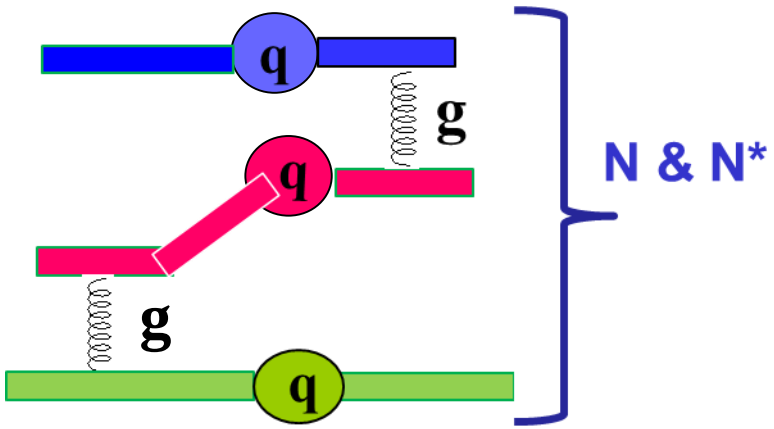
The full complement of resonances expected from the quark models employing SU(6) spin-flavor symmetry (solid line) is needed for consistency with the LQCD description of the phase transition (colored area with symbols).

➡ **Studies of full baryon spectrum are needed**

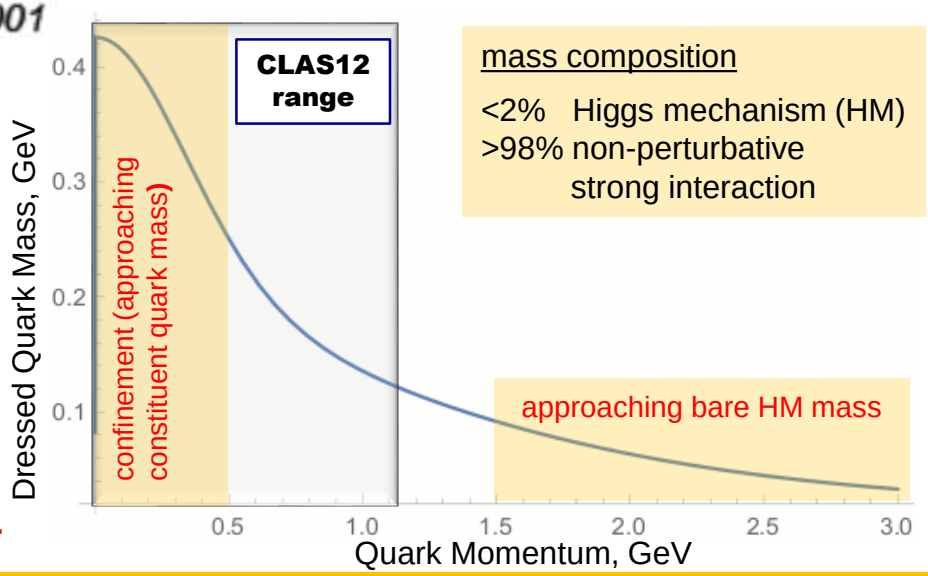
N* structure studies address:

- **Nature of > 98% of hadron mass**
- **Confinement and color charge emergence from QCD**
- **Full complexity of qq- and 3-dressed-quark interactions in baryons**

Dressed Quark Borromeo Binding in Baryons
C.D. Roberts, J. Segovia, Few Body Syst. 57, 1067 (2016)



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



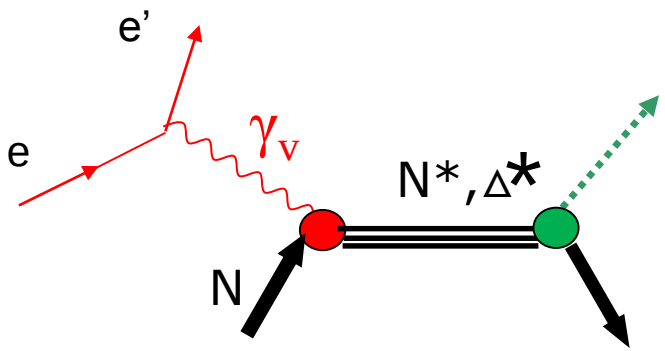
mass composition

<2% Higgs mechanism (HM)
>98% non-perturbative strong interaction

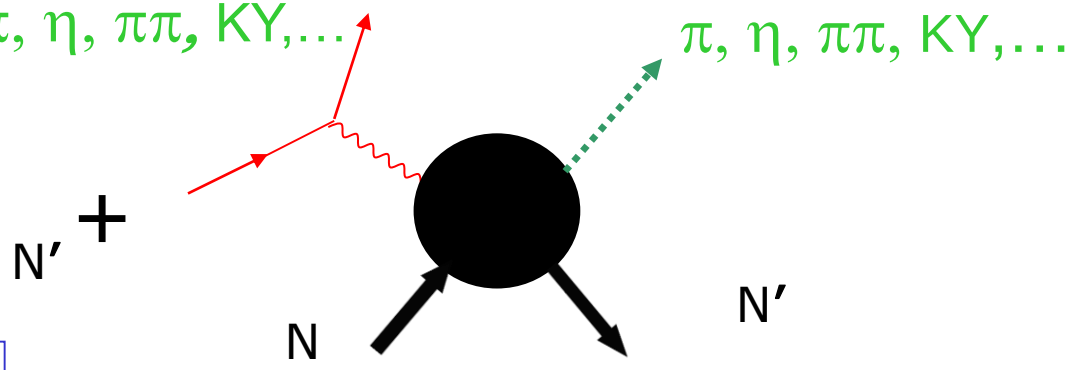
Inferred from QCD Lagrangian with only the Λ_{QCD} parameter

Extraction of γ_vNN* Electrocouplings from Exclusive Meson Electroproduction off Nucleons

Resonant amplitudes



Non-resonant amplitudes



- **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).

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

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

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

- **Consistent results on γ_vNN* electrocouplings from different meson electroproduction channels and different analysis approaches demonstrate reliable extraction of these quantities**

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
π^+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** **$d\sigma/d\Omega$**
π^0p	**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

■ Recent extensions

Almost full coverage of the final hadron phase space in πN, $\pi^+\pi^-p$, ηp, KY electroproduction

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 γ_vNN* Electrocouplings from the CLAS Exclusive Meson Electroproduction Data

Analyses of different exclusive electroproduction channels independently:

- **π^+n and π^0p 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 analyses of the CLAS/world data of $\gamma_{r,v}$N , πN, ηN, $\pi\pi$N, KΛ, KΣ exclusive channels:

T.-S. H. Lee, AIP Conf. Proc. 1560, 413 (2013)

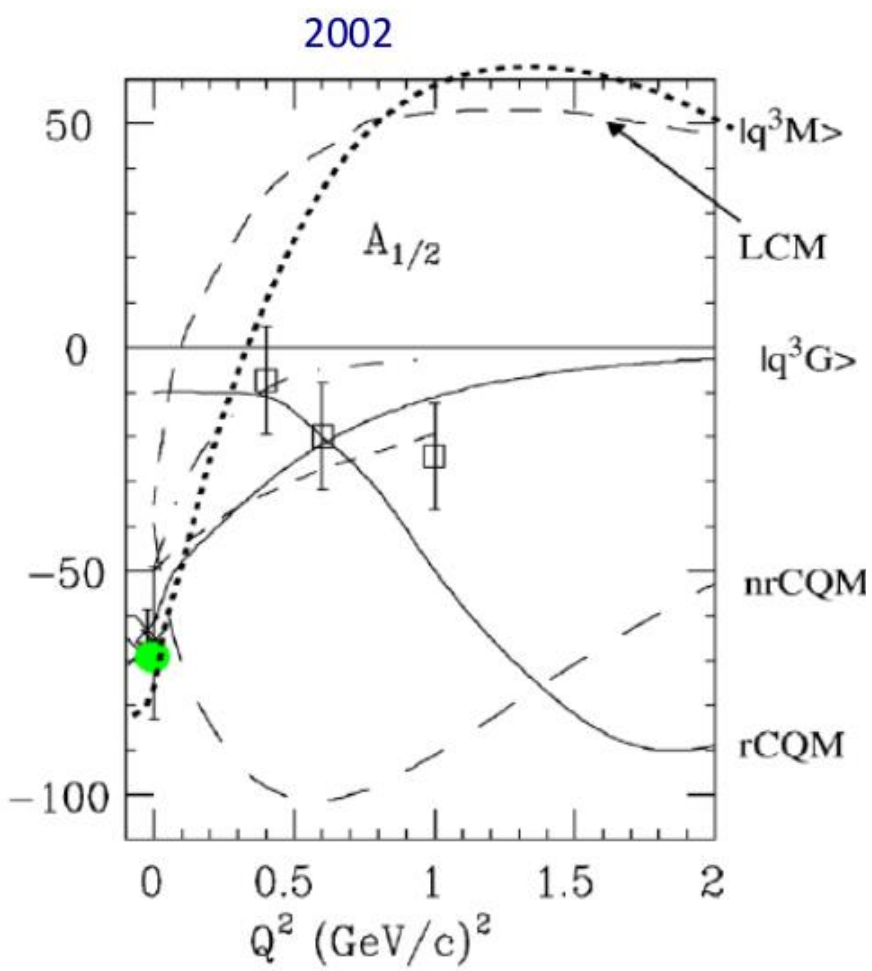
H. Kamano et al., Phys. Rev. C88, 035209 (2013), **H. Kamano NSTAR17 talk, http://nstar2017.physics.sc.edu/**

JPAC Dispersion Relation approach accounting for restrictions from unitarity and analyticity

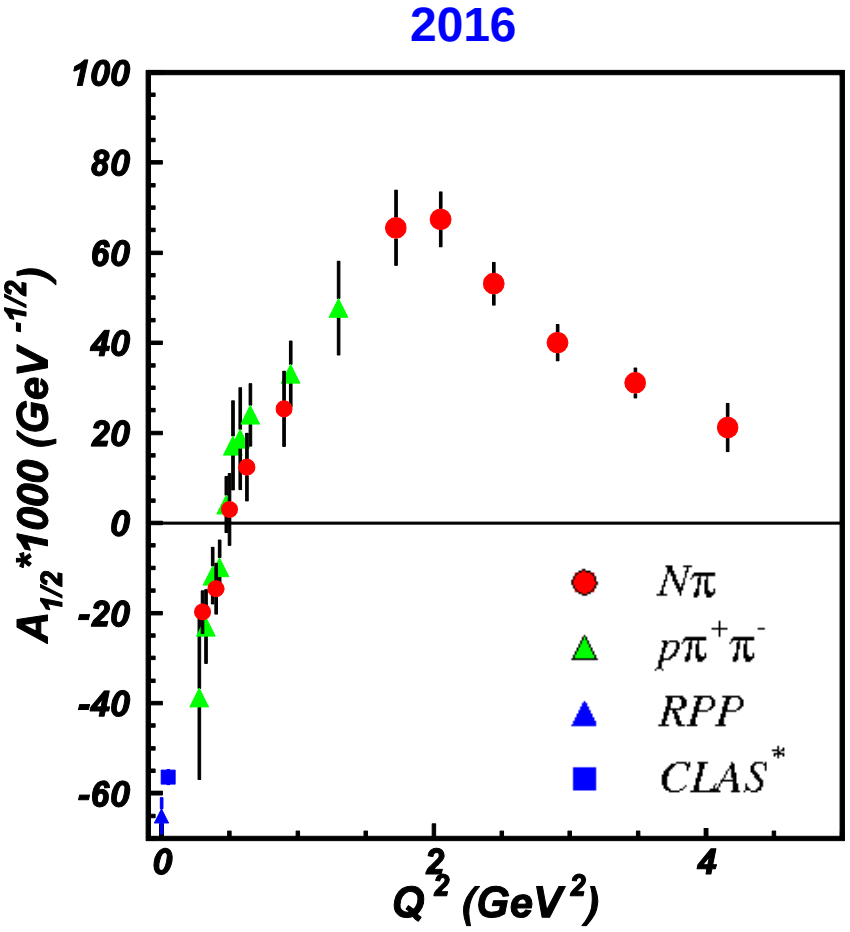
V.Mathieu, J. Nys NSTAR17 talks, http://nstar2017.physics.sc.edu/

- **Resonance parameters from L+P expansion for the PW amplitudes:**
  A.Svarc et al., Phys. Lett. B755, 452 (2016), L. Tiator et al., Phys. Rev. C94, 065204 (2016)

Roper Resonance in 2002 & 2016



V. Burkert, Baryons 2002



V. D. Burkert, Baryons 2016

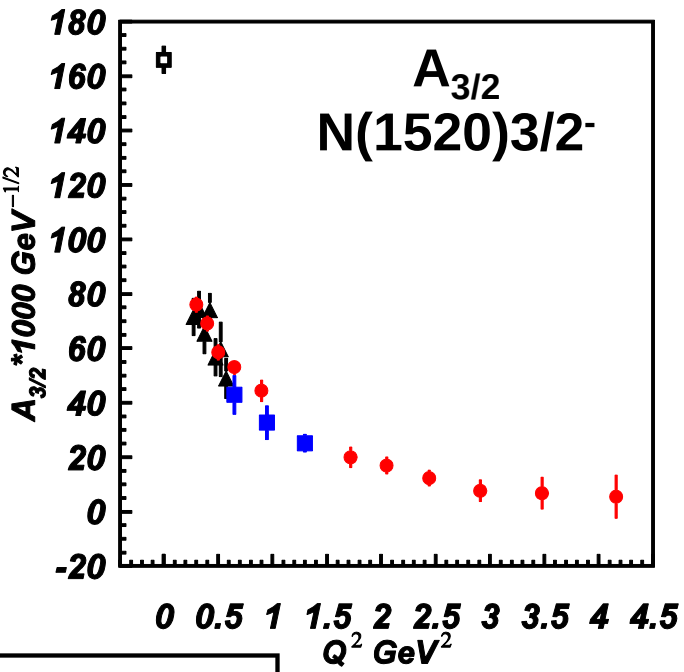
Electrocouplings of Δ(1232)3/2$^+$, N(1440)1/2$^+$, N(1520)3/2$^-$, N(1535)1/2$^-$, N(1675)5/2$^-$, N(1680)5/2$^+$, N(1710)1/2$^+$ were published in the recent edition of the PDG , Chin. Phys. C40, 100001 (2016).

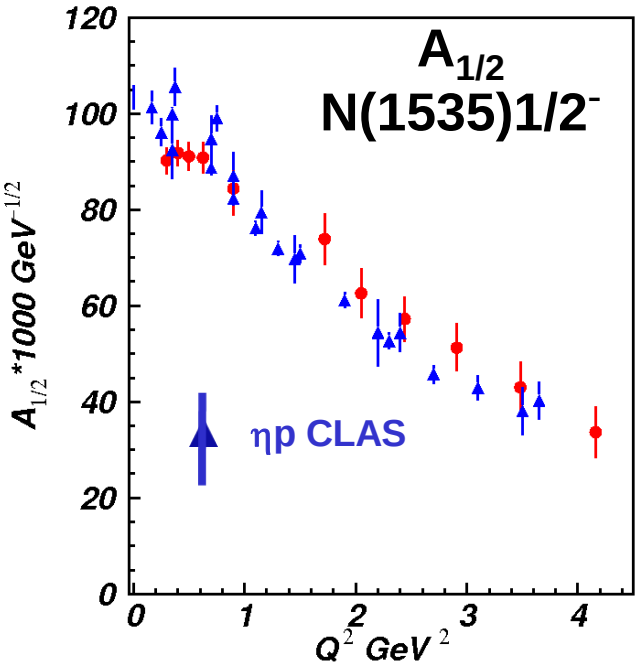
$\gamma_v pN^*$ Electrocouplings from $N\pi$, $N\eta$, and $\pi^+\pi^- p$ Electroproduction

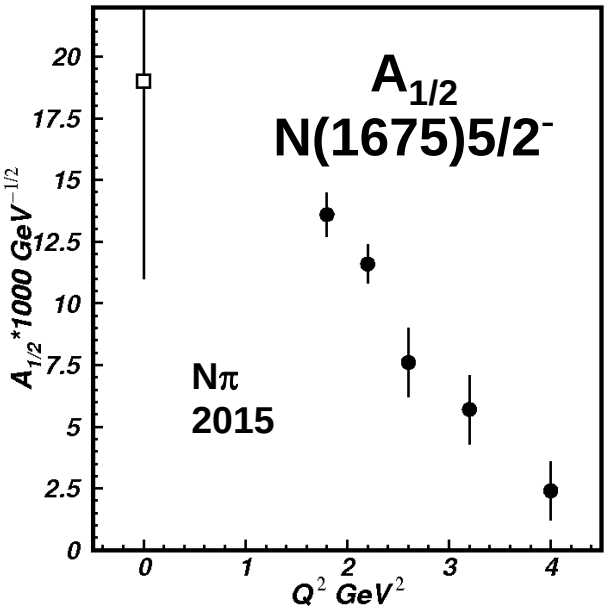
CLAS data:

- $N\pi$ 2009
- $\pi^+\pi^- p$ 2012
- $\pi^+\pi^- p$ 2016
- $N\pi$ 2015

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).







Consistent values of resonance electrocouplings from analyses of $N\pi$, $N\eta$, and $\pi^+\pi^- p$ exclusive channels strongly support:

- **reliable electrocoupling extraction**
- **capabilities of the reaction models to obtain resonance electrocouplings in independent analyses of these channels**

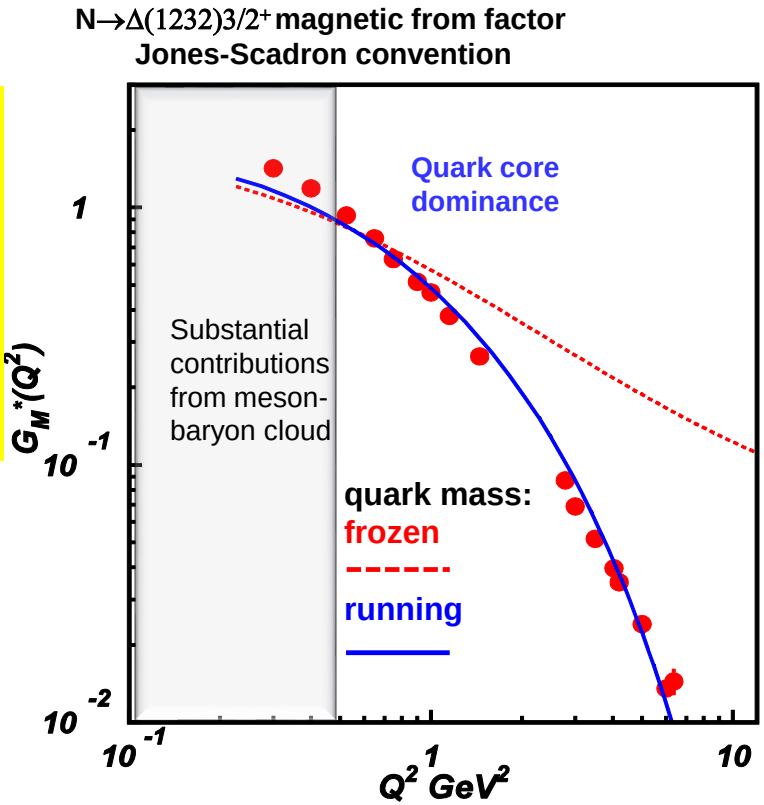
Numerical results on electrocouplings of most N *, Δ* states in the mass range up to 1.8 GeV at Q^2<5.0 GeV^2 are available in:

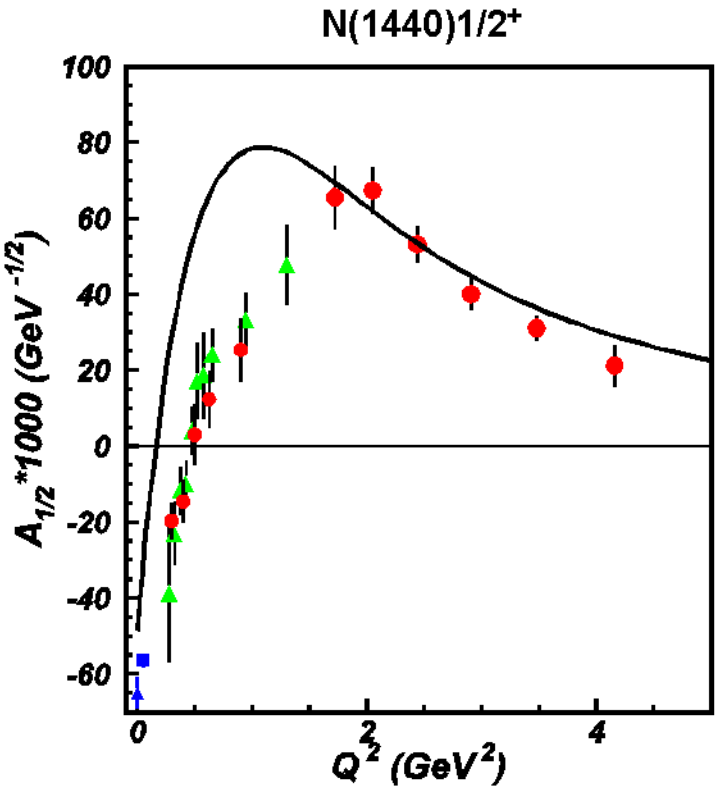
https://userweb.jlab.org/~mokeev/resonance_electrocouplings/,
https://userweb.jlab.org/~isupov/couplings/

Access to the Nature of Hadron Mass

Dyson-Schwinger Equations (DSE):

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





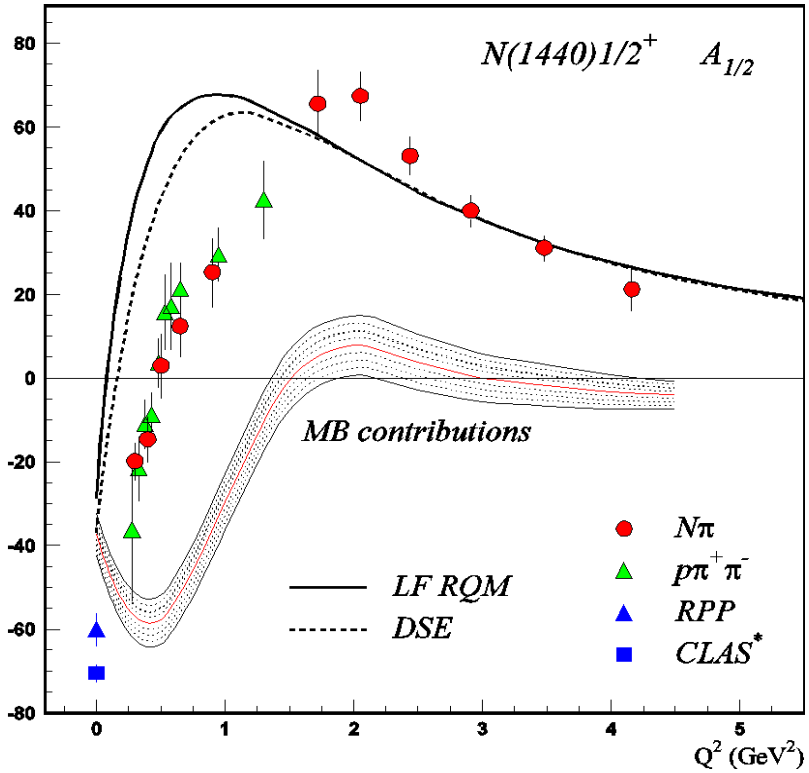
DSE analyses of the CLAS data on Δ(1232)3/2⁺ electroexcitation for the first time demonstrated that dressed quark mass is running with momentum

Good data description at Q^2>2.0 GeV² achieved with the same dressed quark mass function for the ground and excited nucleon states of distinctively different structure provides strong evidence for:

- the relevance of dressed quarks with dynamically generated mass and structure;
- access to quark mass function from the data on elastic and N→N* transition form factors.

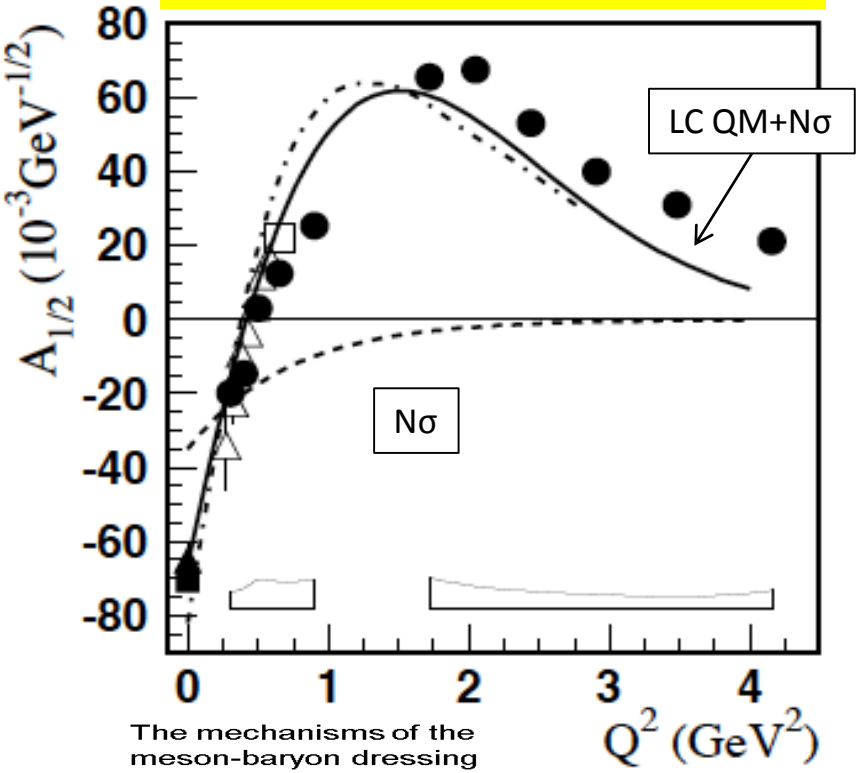
One of the most important achievements in hadron physics of the last decade obtained in synergistic efforts between experimentalists and theorists.

Meson-Baryon Cloud and Quark Core in the N* Structure

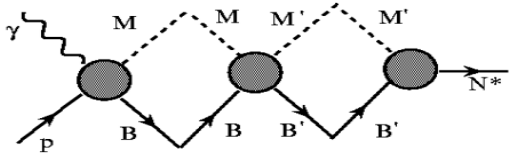


LF RQM-Light Front relativistic quark model: V.D. Burkert, I.G. Aznauryan, Phys . Rev. C85, 055202 (2012); Phys. Rev. C95, 065207 (2017).

I.T. Obukhovsky et al., Phys. Rev. D89, 014032 (2012).

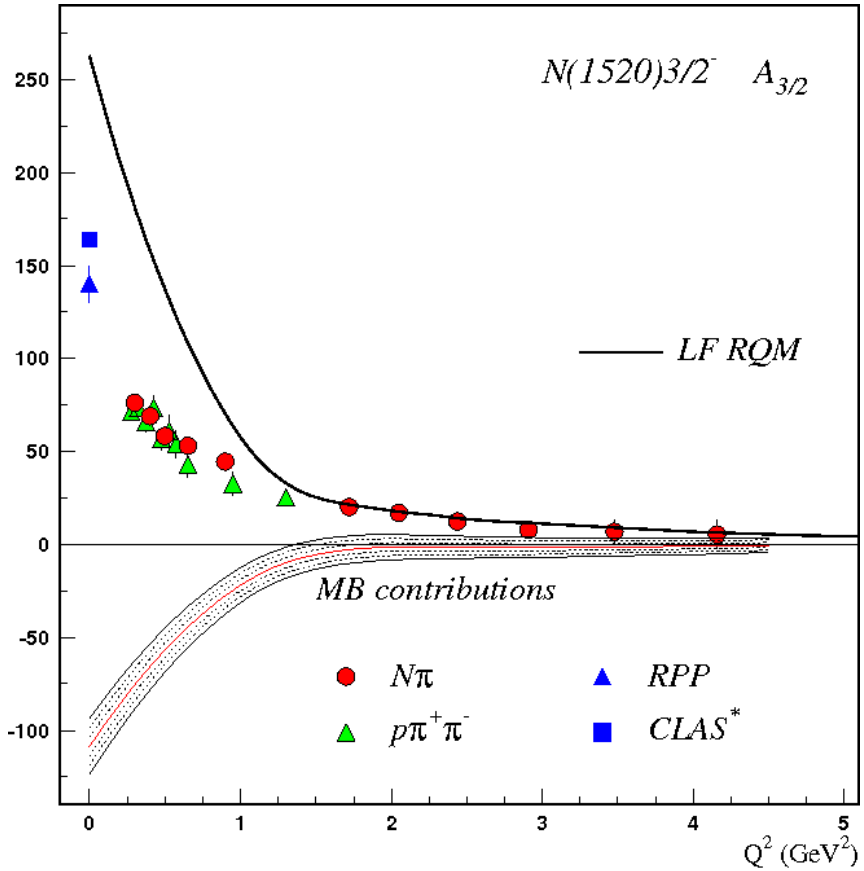


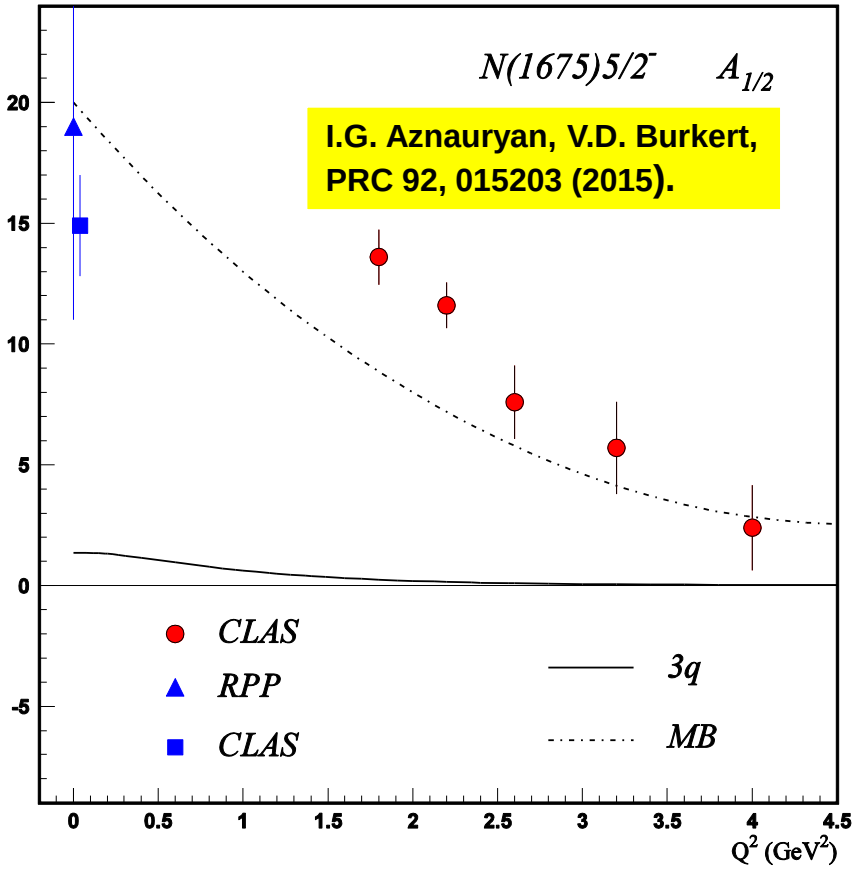
The mechanisms of the meson-baryon dressing



- **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 dressed quarks in the first radial excitation and external MB cloud**
- **Accounting for the MB cloud offers better description of N(1440)1/2$^+$ $A_{1/2}$ amplitude at Q^2<1.0 GeV^2**

Meson-Baryon Cloud and Quark Core in the N* Structure





- **The structure of all studied resonances is determined by a complex interplay between inner core of dressed quarks and external MB cloud. Their relative contributions depend from the resonance quantum numbers.**
- **Relative contributions from MB cloud decreases with Q^2.**

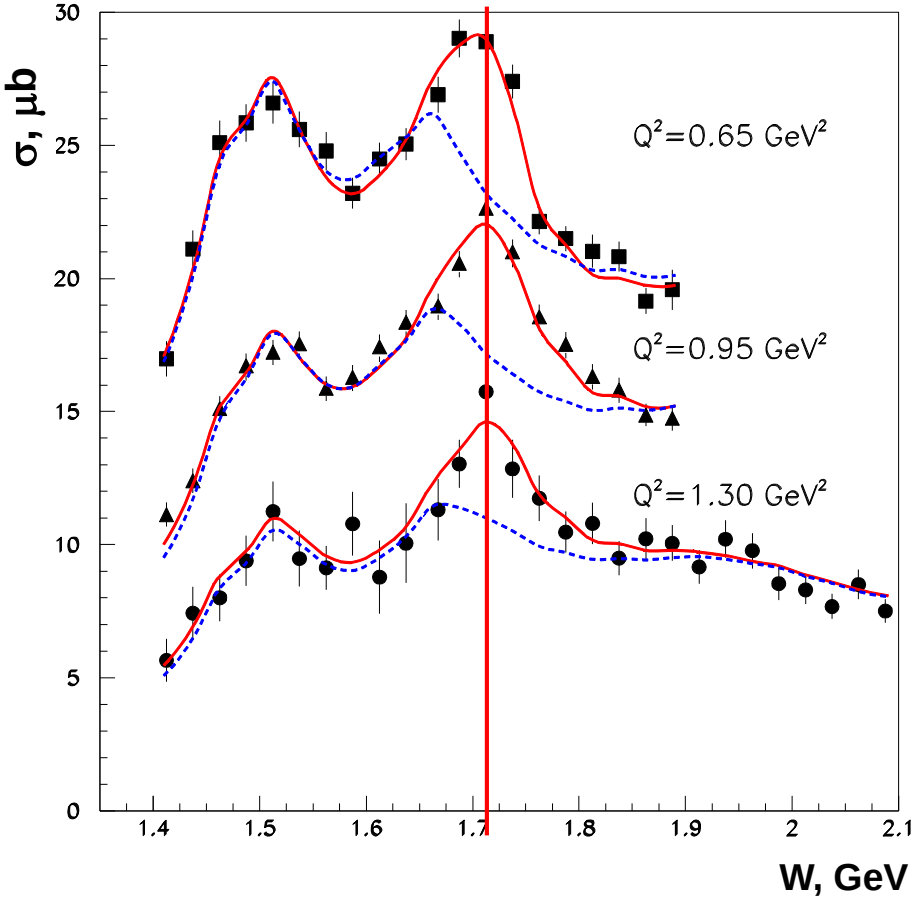
Interpretation of the Structure at W~1.7 GeV from $\pi^+\pi^-$p Electroproduction Data

M.Ripani et al.,CLAS Coll. ,Phys. Rev. Lett. 91,022002 (2003)

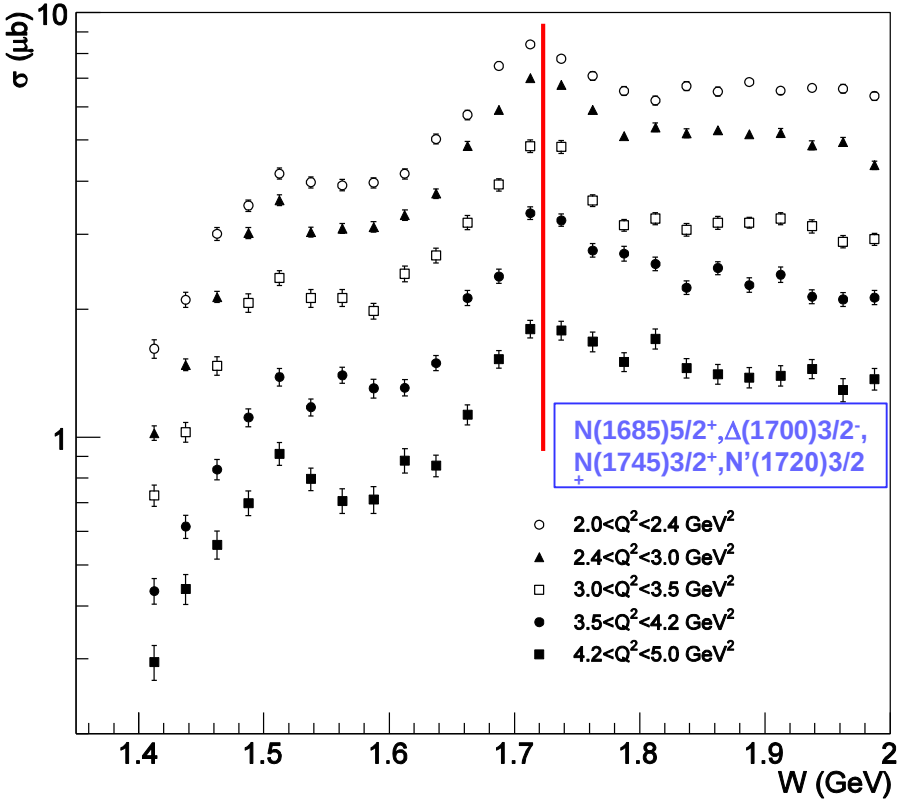
conventional states only, N(1745)3/2⁺ decays mostly to Nρ

implementing N'(1720)3/2⁺ new state or conventional states only with preferential NΔ decays of N(1745)3/2⁺

N(1745)3/2⁺ = N(1720)3/2⁺ from PDG



E.L. Isupov et al., CLAS Coll., Phys. Rev. C96, 025209 (2017)



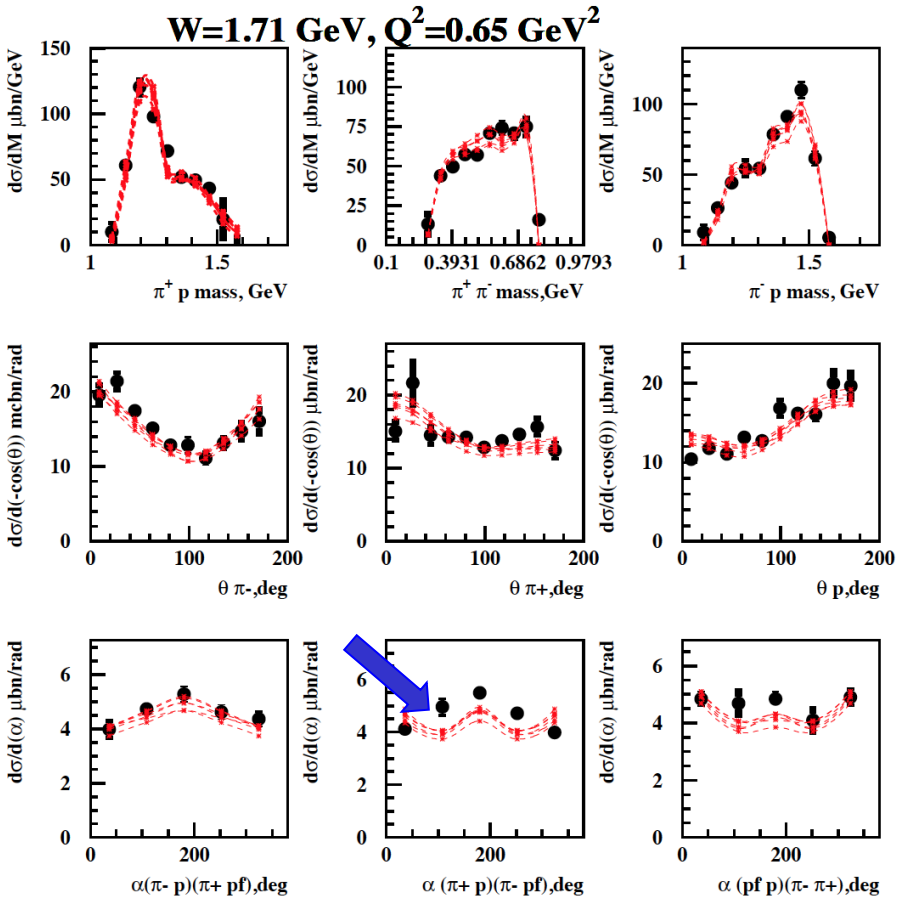
Two equally successful ways for the data description: a) accounting for conventional resonances only, conventional N(1745)3/2⁺ decays mostly to πΔ or b) by implementing new baryon state of close mass N'(1720)3/2⁺ with preferential decays to πΔ, conventional N(1720)3/2⁺ decays both to Nρ and πΔ with comparable branching fractions.

Analysis of the ep→e' $\pi^+\pi^-$p CLAS data at W~1.7 GeV in the JM15 model

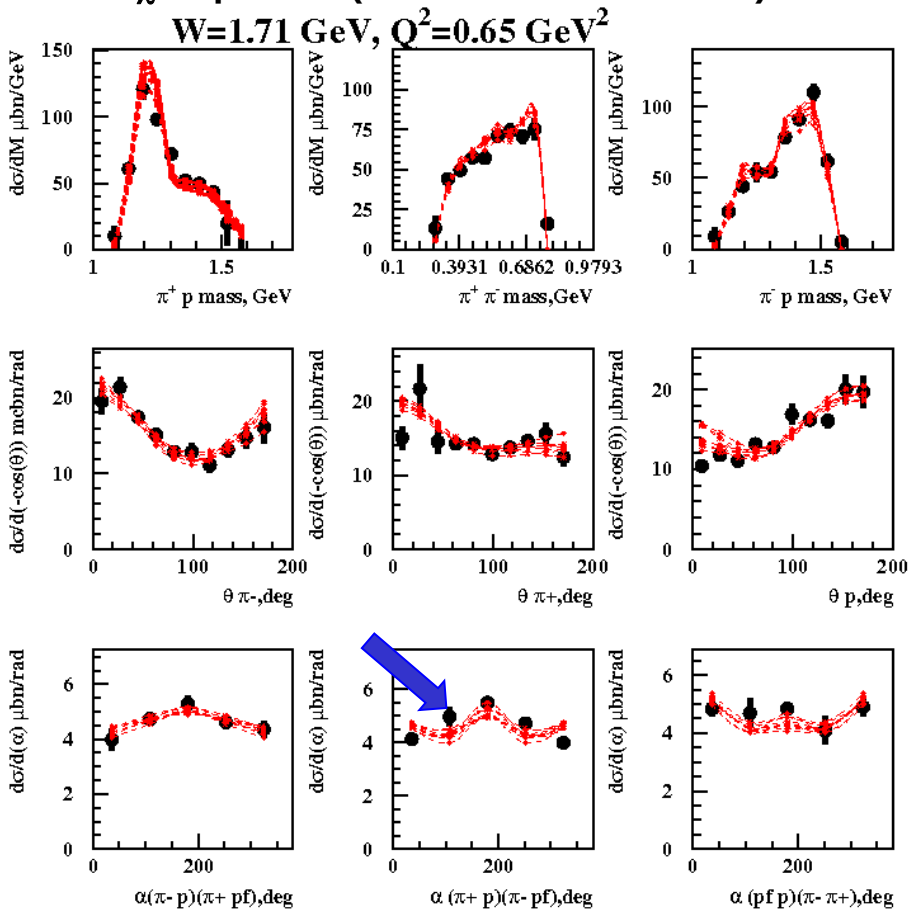
conventional N*-states with electro-, $\pi\Delta$, ρp couplings fit to the data

N'(1720) 3/2$^+$ new state is included to the fit

$2.85<\chi^2/d.p.<3.03$ (1.66 GeV<W<1.76 GeV)



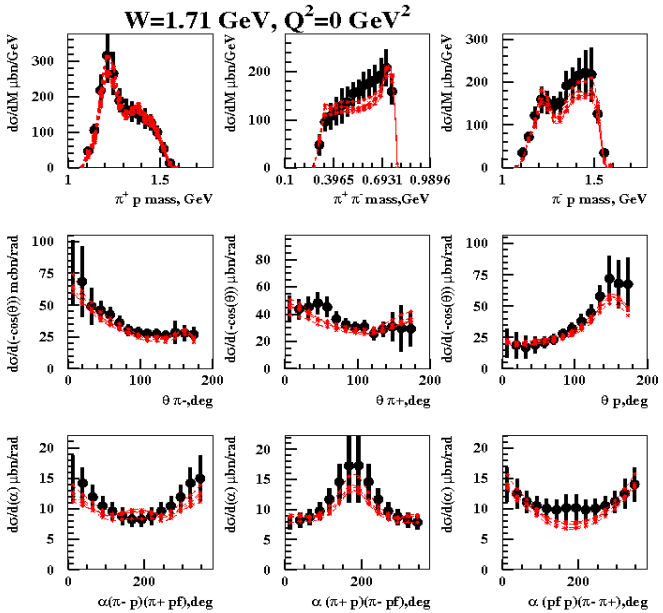
$2.56<\chi^2/d.p.<2.80$ (1.66 GeV<W<1.76 GeV)



- Fit of θ_{π^-}, θ_{π^+}, $\theta_{p'}$ angular distributions requires essential contribution(s) from the resonance(s) of $J^\pi=3/2^+$
- Accounting for the conventional states only, N(1745)3/2$^+$ resonance should have major $\pi\Delta$ (>60%) and minor ρp (<5%) decays in order to reproduce pronounced Δ–peaks in π^+p and to avoid the ρ-peak formation in $\pi^+\pi^-$ mass distributions
- Accounting for both new N'(1720) 3/2$^+$ and conventional N(1745)3/2$^+$ states makes the $\pi\Delta$ and ρp decays of N(1745)3/2$^+$ comparable and allow better description of $\alpha_{[\pi+p][\pi-p']}$ CM-angular distributions

Strong Evidence for the Existence of the New State N'(1720)3/2$^+$ from $\pi^+\pi^-$p Analyses in both Photo- and Electroproduction

E.N. Golovach, CLAS Coll.,
$\gamma p \to \pi^+\pi^- p$ preliminary



N(1745)3/2$^+$ hadronic decays from the CLAS data fit with conventional resonances only

	BF($\pi\Delta$), %	BF(ρp), %
electroproduction	64-100	<5
photoproduction	14-60	19-69

The contradictory BF values for N(1745)3/2$^+$ decays to the $\pi\Delta$ and ρp final states deduced from photo- and electroproduction data make it impossible to describe the data with conventional states only

Almost the same quality of the photoproduction data fit was achieved with and without N'(1720)3/2$^+$ new state

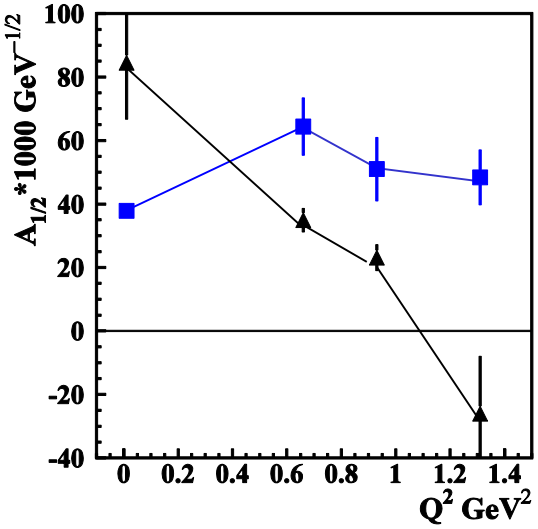
N* hadronic decays from the data fit that incorporates the new N'(1720)3/2$^+$ state

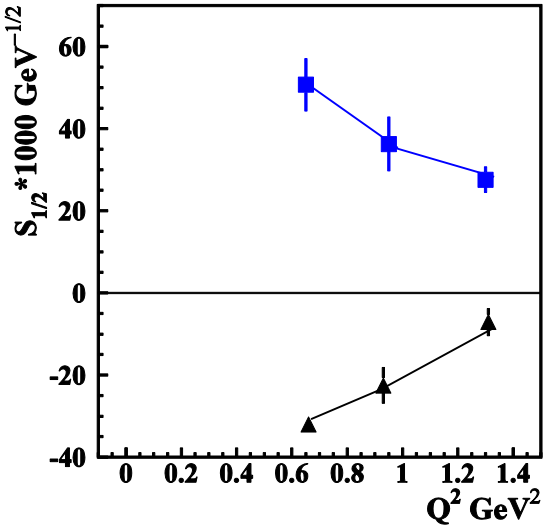
Resonance	BF($\pi\Delta$), %	BF(ρp), %
N'(1720)3/2$^+$		
electroproduction	47-64	3-10
photoproduction	46-62	4-13
N(1745)3/2$^+$		
electroproduction	39-55	23-49
Photoproduction	38-53	31-46
Δ(1700)3/2$^-$		
electroproduction	77-95	3-5
photoproduction	78-93	3-6

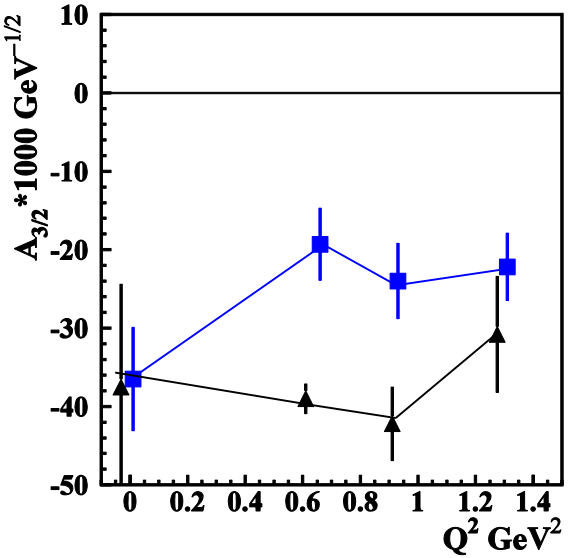
Successful description of $\pi^+\pi^-$p photo- and electroproduction data achieved by implementing new N'(1720)3/2$^+$ state with Q^2-independent hadronic decay widths of all resonances contributing at W~1.7 GeV provides strong evidence for the existence of new N'(1720)3/2$^+$ state.

The Parameters of N'(1720)3/2$^+$ New State from the CLAS Data Fit

The photo-/electrocouplings of N'(1720)3/2$^+$ and conventional N(1745)3/2$^+$ states:







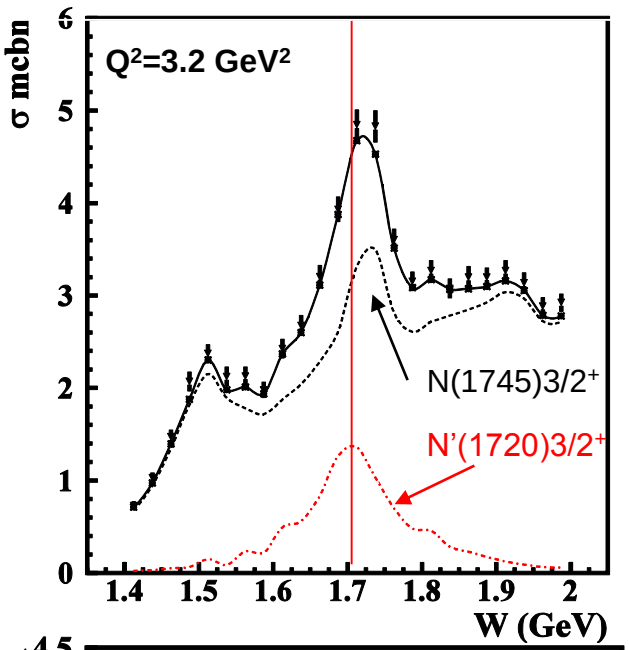
N'(1720)3/2$^+$

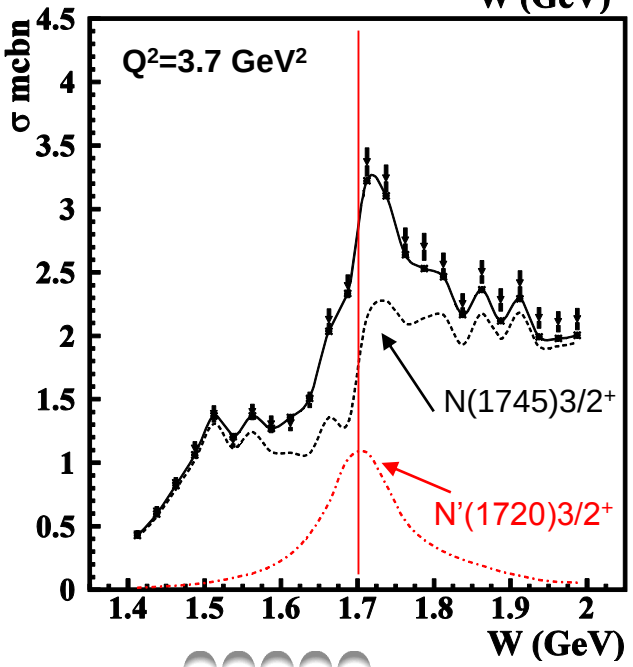
N(1745)3/2$^+$

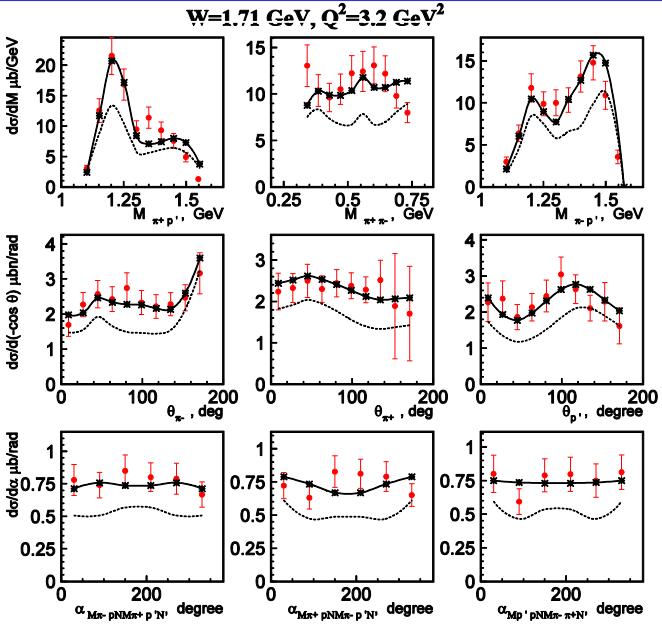
Resonance	Mass, GeV	Total width, MeV
N'(1720)3/2$^+$	1.715-1.735	120±7
N(1745)3/2$^+$	1.743-1.753	114±9

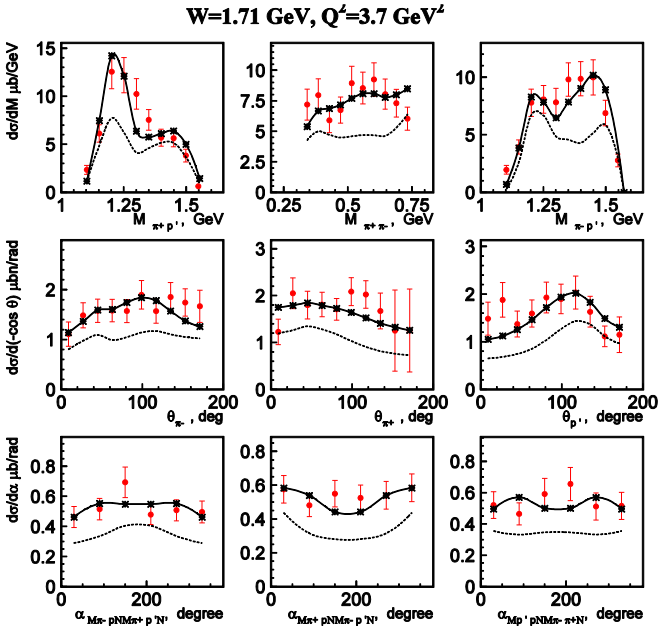
N'(1720)3/2$^+$ is the only candidate state for which the results on Q^2-evolution of transition electrocouplings have become available offering the insight to the structure of the new baryon state

Signals from N'(1720)3/2⁺ New State in the CLAS ep→e'π⁺π⁻p Data at 2.0 <Q²<5.0 GeV²









Data description in the JM17 model:

——— **full**

- - - - - - - - **no N'(1720)3/2⁺**

- - - - - - - - **difference with / without N'(1720)3/2⁺**

Clear manifestation of N'(1720)3/2⁺ new state

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 KΛ, Nππ, Nπ *(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.S. Carman et al.)*

Approved by PAC44

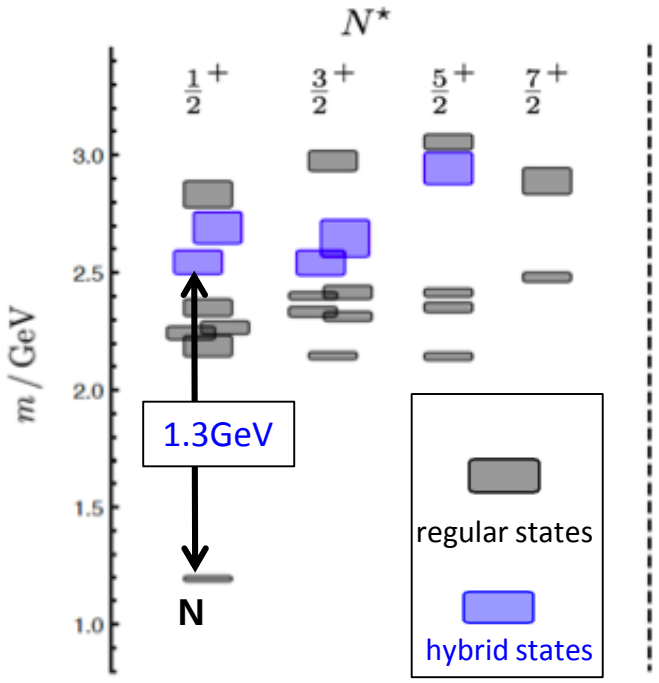
Run Group conditions:
E_b = 6.6 GeV, 50 days
E_b = 8.8 GeV, 50 days

- Polarized electrons, unpolarized LH_2 target
- L = 1x10^{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?

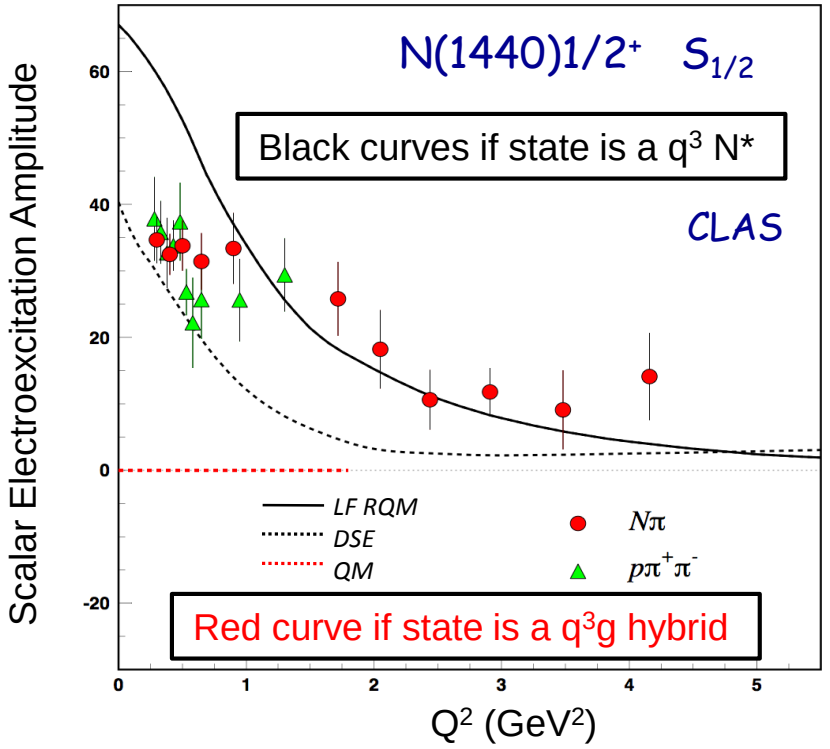
Predictions of the N* spectrum from QCD show both regular q^3 *and* hybrid q^3g states



JLab LQCD group results

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

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



CLAS12 N* Program at High Q^2

E12-09-003	E12-06-108A
Nucleon Resonance Studies with CLAS12	KY Electroproduction with CLAS12
Gothe, Mokeev, Burkert, Cole, Joo, Stoler	*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 the almost 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 foreseen in the world capable to map-out N quark core under almost negligible contributions from meson-baryon cloud*

The experiments will start at the end of 2017!

Emergence of Hadron Mass and Quark-Gluon Confinement

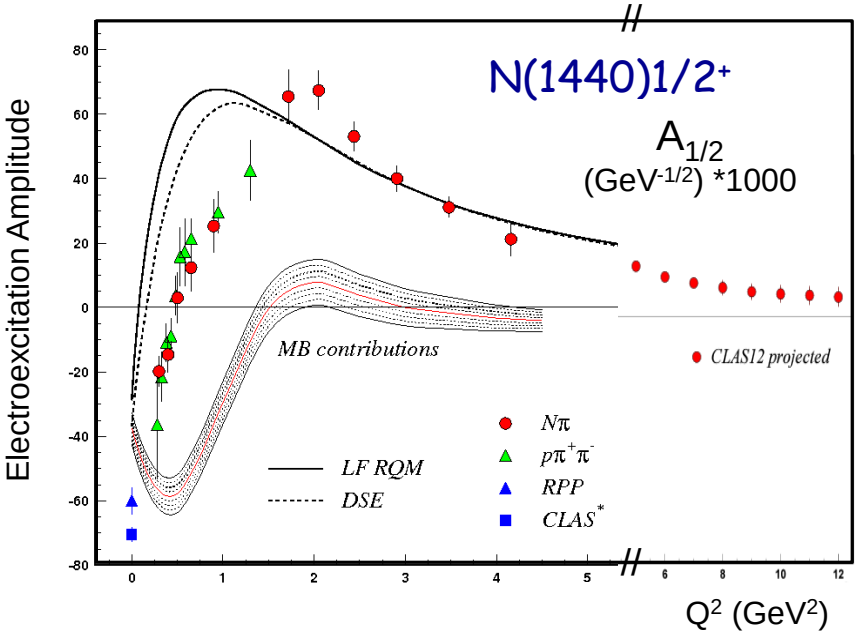
N* electroexcitation studies with CLAS12 in Hall B at JLab will address the critical open questions:

How is >98% of visible mass generated?

How confinement emerges from QCD and how it is related to DCSB?

Reveal the structure of QCD's running coupling at infrared momenta.

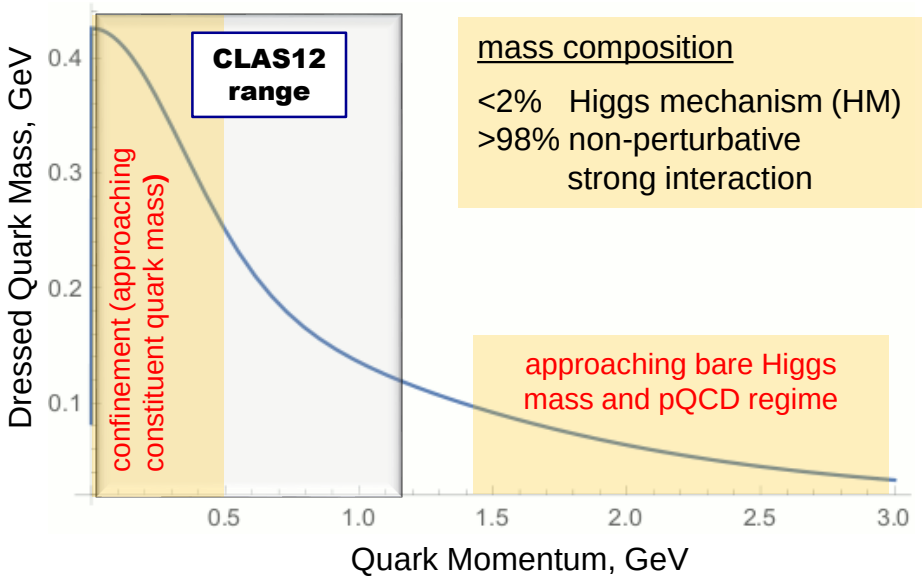
Mapping-out quark mass function from the CLAS12 results on $\gamma_v pN^*$ electrocouplings of spin-flavor flip, radial, and orbital excited nucleon resonances at $5<Q^2<12$ GeV^2 will allow us to explore the transition from strong QCD to pQCD regimes with a traceable connection to the QCD Lagrangian.



CLAS results vs. theory expectations with running quark mass

Access to the dressed quark mass function

C.D. Roberts, Few Body Syst. 58, 5 (2017),
C.D. Roberts, JPC Conf. Proc 10, 010012 (2016).



Conclusions and Outlook

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

- **CLAS data revealed the structure of excited nucleon states as a complex interplay between inner core of three dressed quarks and external meson-baryon cloud with the contributions dependent from the resonance quantum numbers.**

- **<u>Profound impact on the exploration of strong QCD dynamics:</u>**
  a) first DSE evaluations of $\Delta(1232)3/2^+$ and $N(1440)1/2^+$ electroexcitation amplitudes with a traceable connection to the QCD Lagrangian;
  b) synergistic efforts between the experimental studies of $\gamma_v pN^*$ electrpocouplings in Hall B at JLab (V.D. Burkert) and the continuous QCD theory (C.D. Roberts) have revealed the capability for reliable access to quark mass function for the first time.

- **To describe both the $\pi^+\pi^-p$ photo- and electroproduction data demands including the new baryon state $N'(1720)3/2^+$. Successful description of these data with Q^2-independent hadronic decay widths to the $\pi\Delta$ and ρp final states of all contributing resonances <u>provides strong evidence for the existence of $N'(1720)3/2^+$ new baryon state.</u>**

- **High-level physics interpretation of resonance parameters is a very difficult task. Intensive efforts are underway within DSE, LQCD and quark models to the many challenges.**

Conclusions and Outlook

- **After 12 GeV Upgrade, CLAS12 will be only available worldwide facility capable of obtaining electrocouplings of all prominent N* states at still unexplored ranges of low photon virtualities down to 0.05 GeV^2 and highest photon virtualities ever achieved for exclusive reactions from 5.0 GeV^2 to 12 GeV^2 from the measurements of exclusive Nπ, $\pi^+\pi^-$p, and KΣ, KΛ electroproduction.**

- **The expected results will allow us:**
  a) 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 the emergence of quark-gluon confinement and color charge from QCD.

- **Success of N* Program with the CLAS12 detector at Jefferson Lab will be very beneficial for 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

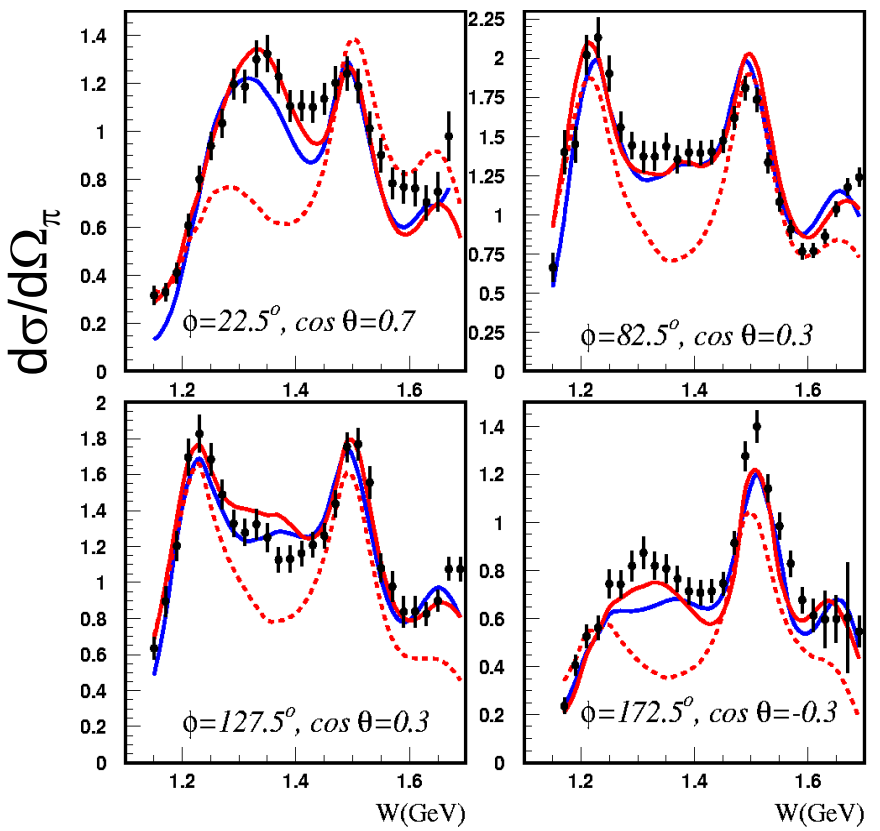
Fits to $\gamma_v p \to \pi^+ n$ Differential Cross Sections and Structure Functions

Q^2=2.05 GeV^2

DR

DR w/o P11

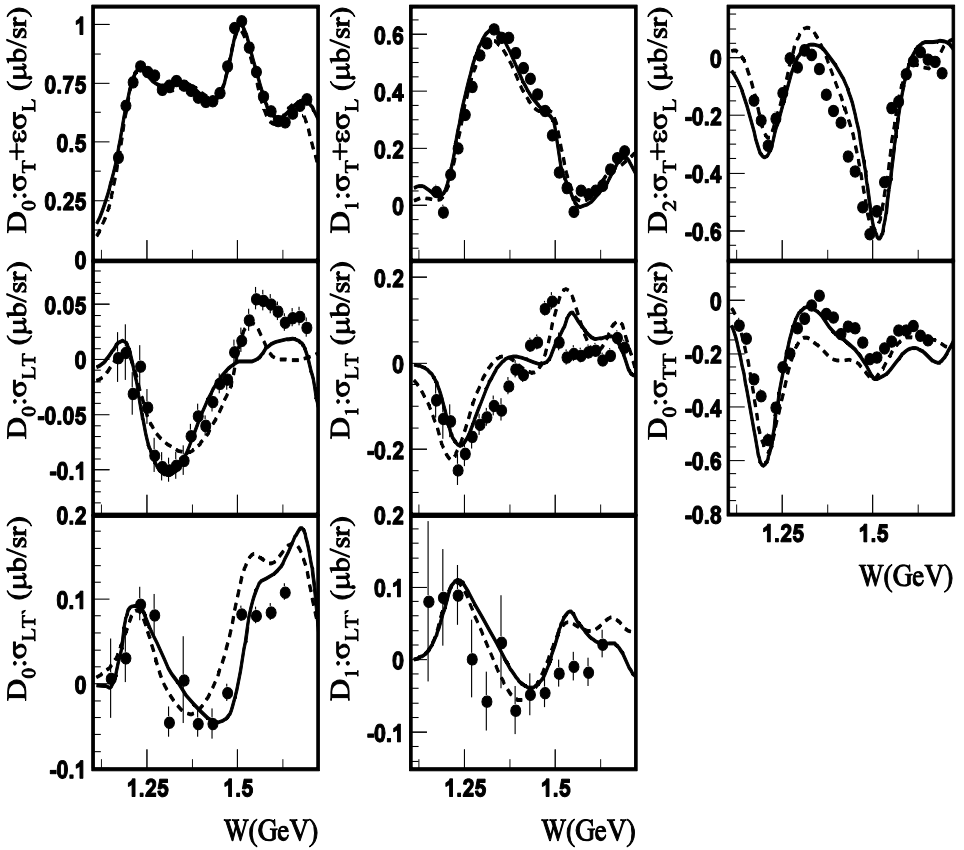
UIM



Q^2=2.44 GeV^2

DR

UIM

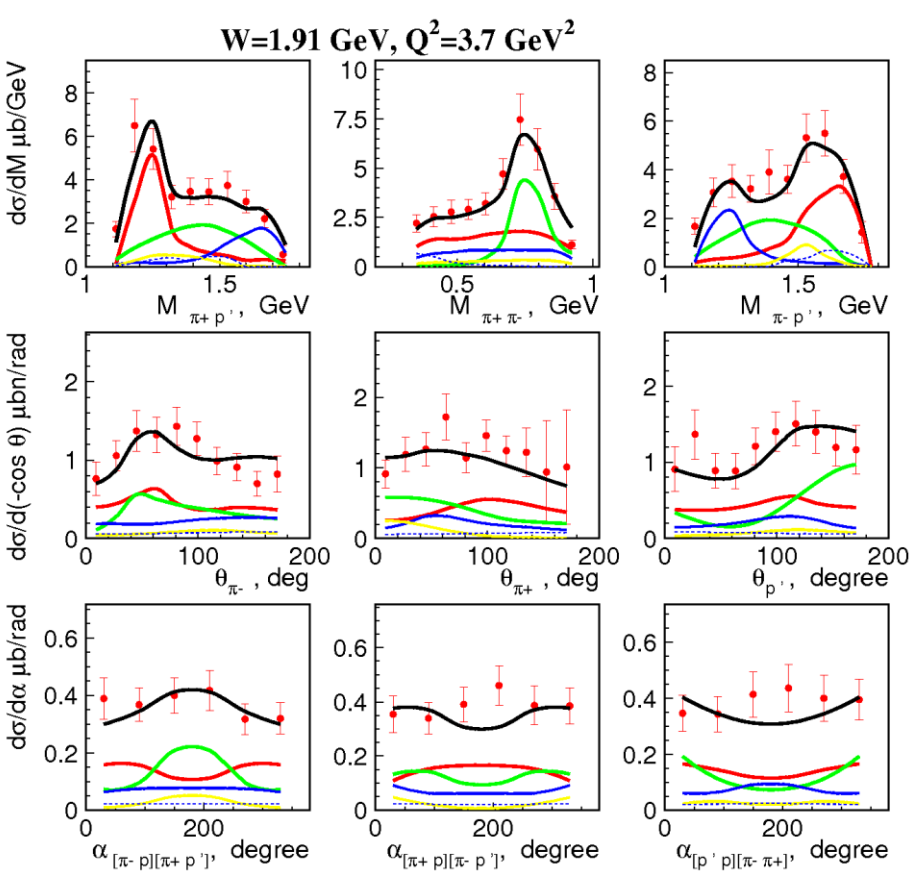


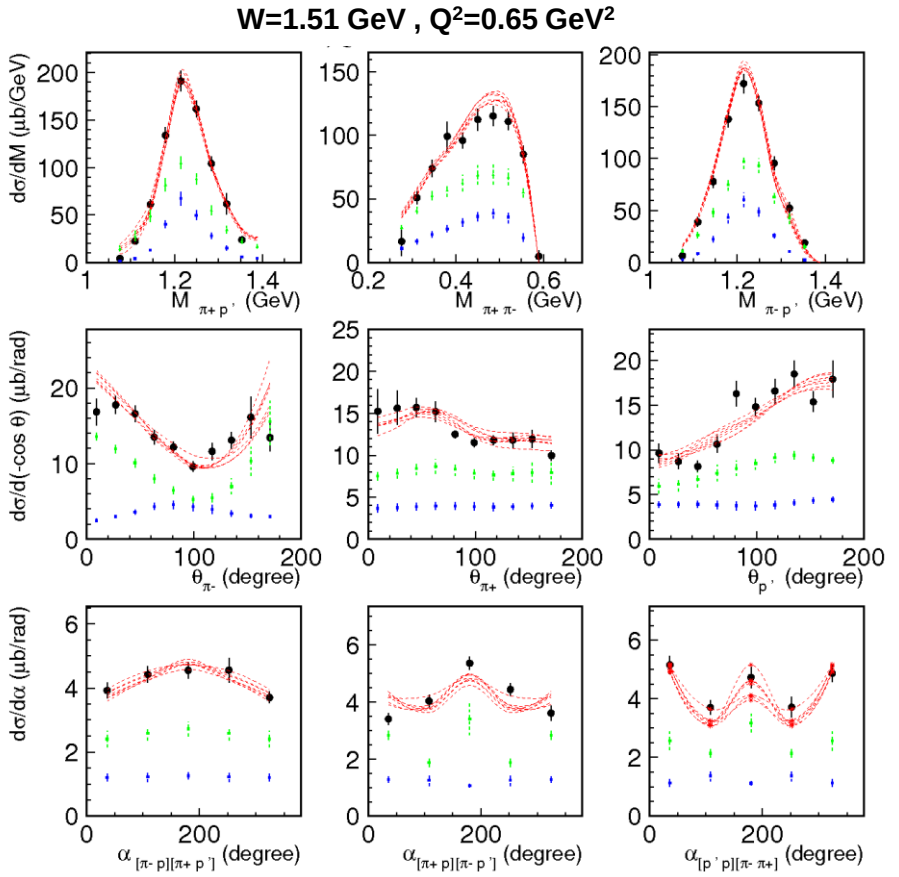
Legendre moments D_l (l=0,1,2) from various structure functions

Resonance Parameter Extraction from the CLAS $\pi^+\pi^-p$ Differential Cross Sections within the Meson-Baryon Reaction Model JM

E.L. Isupov et al (CLAS), in press by PRC
Contributing mechanisms seen in the data

V.I. Mokeev et al, PRC 93 (2016), 025206
Resonant and non-resonant contributions





full JM — ρp — π^+ N(1520)3/2$^-$ — data fit within JM under variations of both resonant and background parameters

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

resonant cross sections

Peculiarities in the Structure of $\Delta(1620)1/2^-$

- **Only known resonance with dominant longitudinal electroexcitation at $Q^2>0.5$ GeV^2 .**
- **QM with three quarks only failed in describing the resonance electrocouplings**

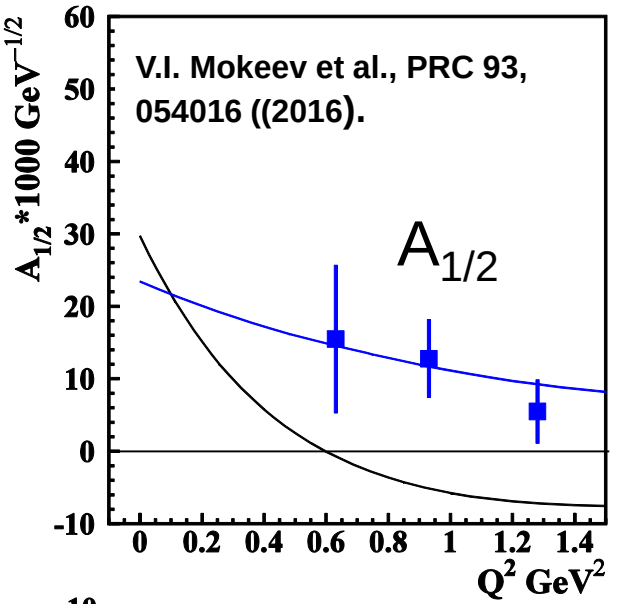
Hadron decays from the CLAS $\pi^+\pi^-p$ electroproduction data

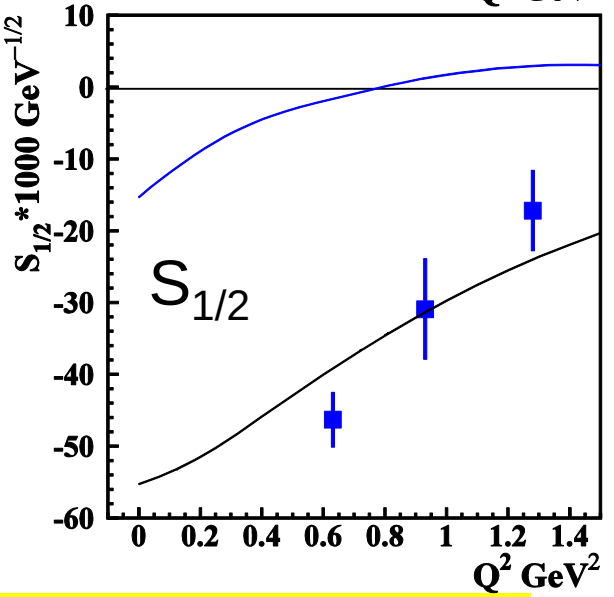
Channel	Branching Fraction, %
$\pi\Delta$	27-64
ρp	31-63

Large ρp decay in the sub-threshold region

Suggestive for a substantial contribution from ρp loops :

- **either to the MB-cloud or as**
- **penta-quark admixture in the quark core**



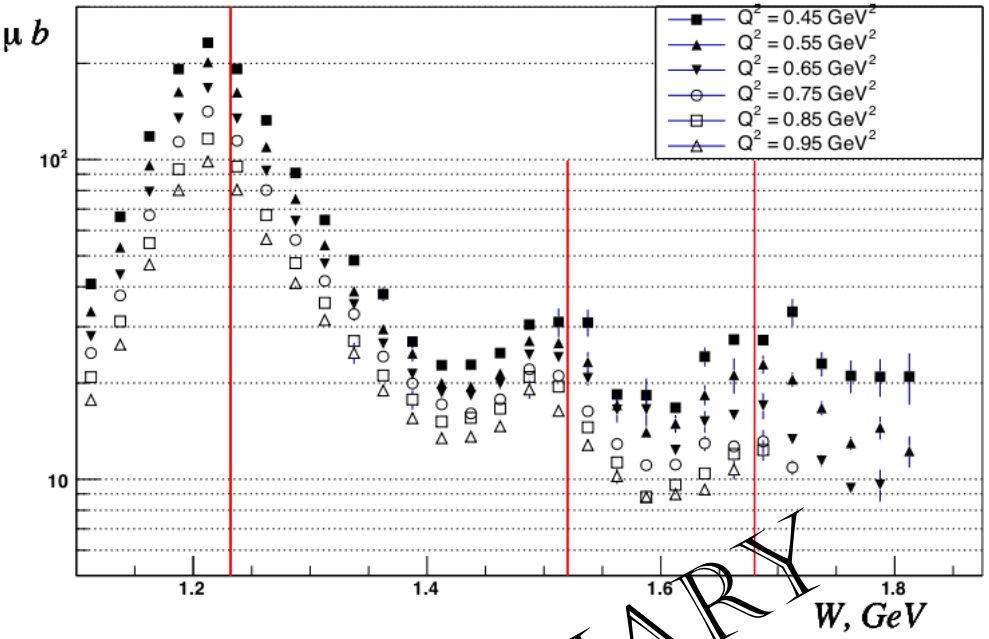


Hypercentral CQM: E.Santopinto, M.Giannini, PRC 86, 065202 (2012).

Bethe-Salpeter CQM M.Ronninger, B.Ch.Metsch,EPJ, A49, 8 (2013).

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

Fully integrated cross sections



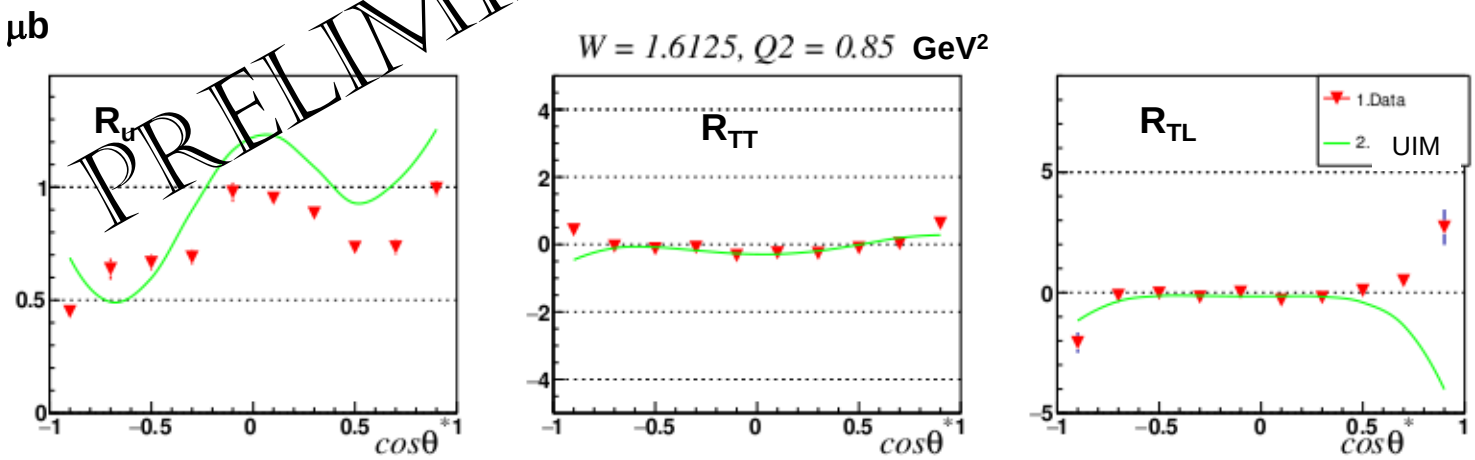
N. Markov, K.Joo, UCONN

1.10GeV<W<1.80 GeV,
0.3 GeV^2<Q^2<1.0 GeV^2

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 Nπ final state.

PRELIMINARY

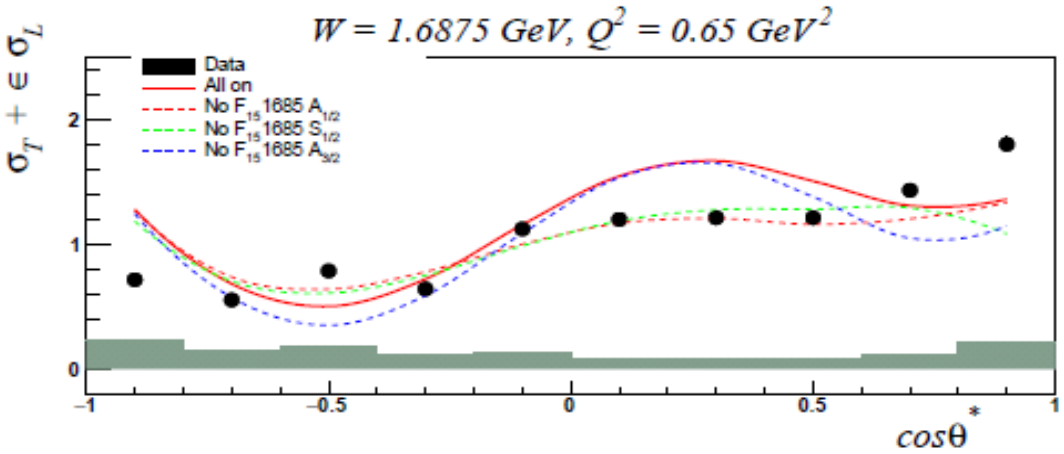
The structure functions



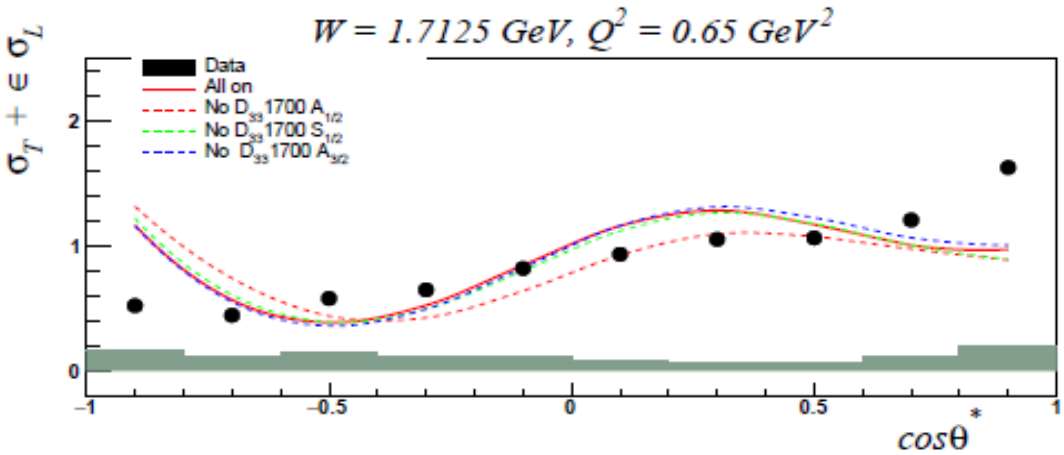
Structure of the Excited Nucleon States in the 3rd Resonance Region from $\pi^0 p$ Electroproduction off Protons

- $\gamma_v pN^*$ 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 Δ(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.

Expected Results from the CLAS on $\gamma_v pN^*$ Electrocouplings and their Impact on the Insight to Strong QCD

- **Electrocouplings of most N* in the mass range <2.0 GeV will become available from independent studies of $N\pi$ and $\pi^+\pi^- p$ electroproduction off protons at $Q^2<5.0$ GeV^2 in near term future (see Sessions A4, A5) ; expected results from KY electroproduction will be discussed in the talk by D.S. Carman (P7).**

- **Studies of the interplay between meson-baryon and quark degrees of freedom for all prominent resonances in the N* spectrum. Lattice QCD offers the promising avenue to explore all relevant degree of freedom in the N* structure from the first principles of QCD (see talks by Jia Jun Wu (P7), R. Briceno (B1), D. Wilson (B2))**

- **Manifestation of new baryon states in exclusive electroproduction processes.**

- **Studies of the universality/(environmental sensitivity) of the dressed quark mass function from the CLAS results on electroexcitation amplitudes of the $N(1535)1/2^-$, $\Delta(1700)3/2^-$, and $N(1520)3/2^-$ resonances at 2.0 GeV$^2<Q^2<5.0$ GeV^2 (see talk by A.Bashir (B4)).**

- **Access to di-quark correlations of $J^\pi=0^-,1^-$ from the CLAS results on electrocouplings of the $[70,1^-]$, $[56,2^+]$-supermultiplet resonances, insight to complexity of dressed quark-gluon vertex (see talk by J. Rodriguez-Quintero (B4)) .**

- **Studies of dynamical chiral symmetry breaking manifestation in the CLAS results on Q^2-evolution of the chiral-parity partner electrocouplings: $N(938)1/2^+$ vs $N(1535)1/2^-$ and $\Delta(1232)3/2^+$ vs $\Delta(1700)3/2^-$.**

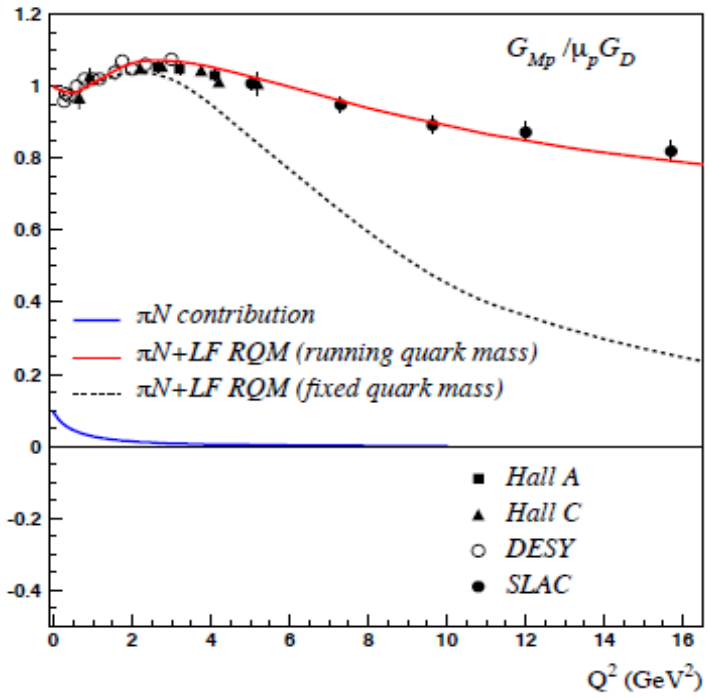
Quark Model with Input from QCD-based Approaches

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.

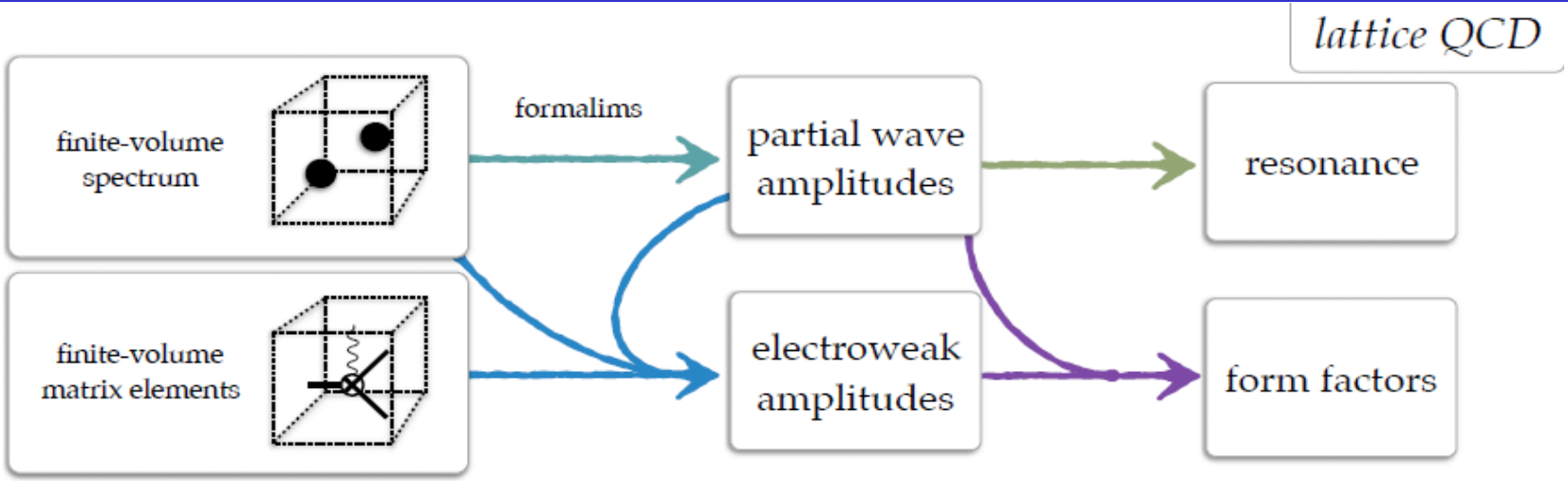
Proton Magnetic Form Factor



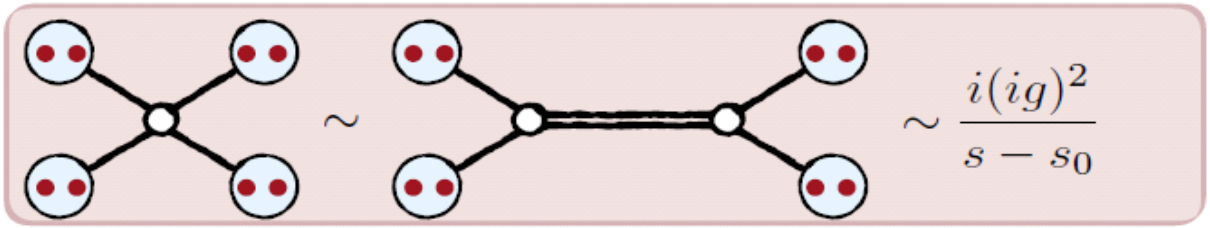
- Nucleon electromagnetic form factors
  → $q^3 + \pi N$ loops contributions in light-front dynamics
  → running quark mass
- Electroexcitation of $\Delta(1232)\frac{3}{2}^+$, $N(1440)\frac{1}{2}^+$, $N(1520)\frac{3}{2}^-$, and $N(1535)\frac{1}{2}^-$
  → q^3 contribution in a LF RQM with running quark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

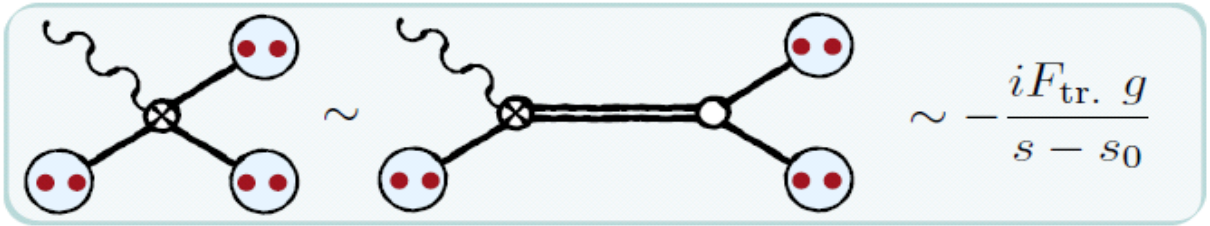
Resonance Structure from Lattice QCD



- *Obtain masses and width*



- *Obtain transition form factors*

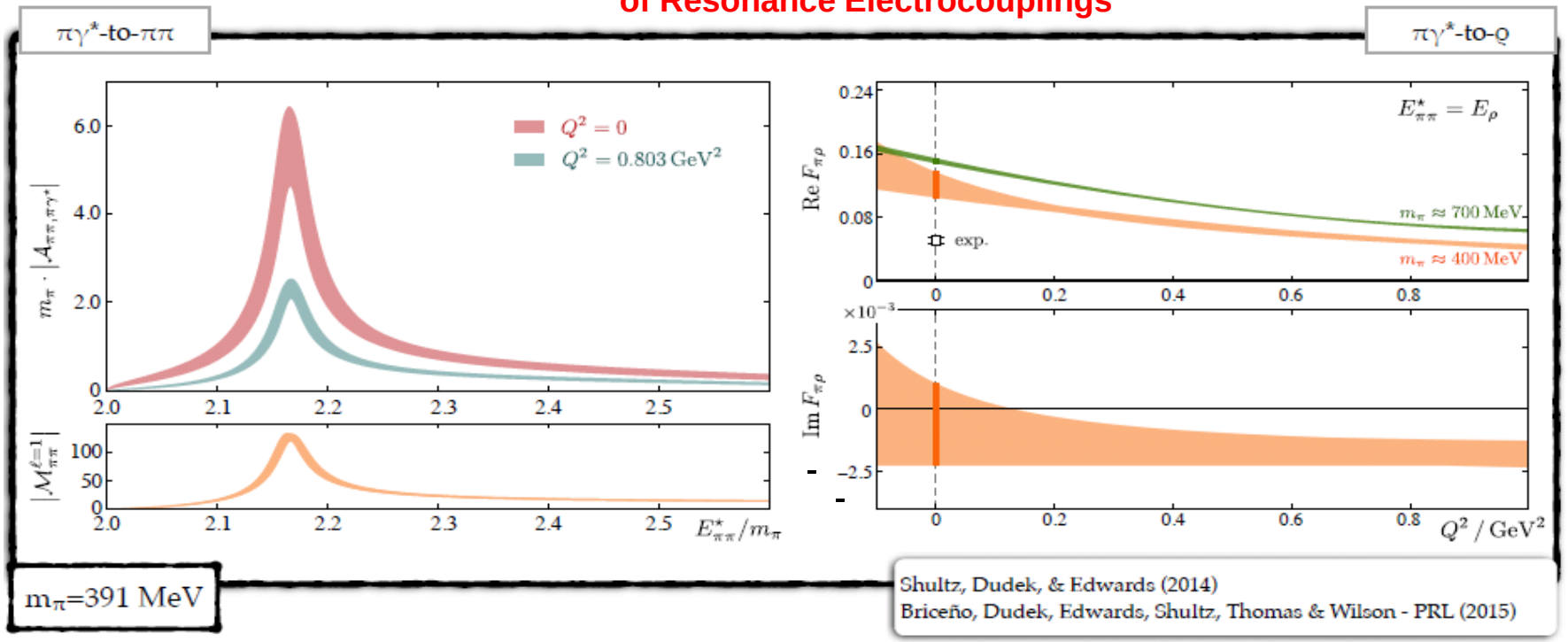


LQCD offers the only way to explore emergence of the N* generation mechanisms from the first principles of QCD accounting for *all* relevant components in the N* structure.

Towards $\gamma_v pN^*$ Electrocoupling Evaluation within LQCD

- Only one calculation to date

See the talk by D.G. Richards - LQCD Prospects for Evaluation of Resonance Electrocouplings



- Framework is universal
  - It is applicable for N-to-N* transitions
  - First one needs to calculate N* spectrum **[effort is underway!]**

- **Implementation of the multi-particle operators for the two-meson-baryon final states in order to obtain electrocouplings of resonances heavier than $\Delta(1232)3/2^+$.**
- **Complementarity in the photon virtuality coverage for the LQCD (Q^2<3.0 GeV^2) and the DSE (2.0<Q^2<12 GeV^2).**