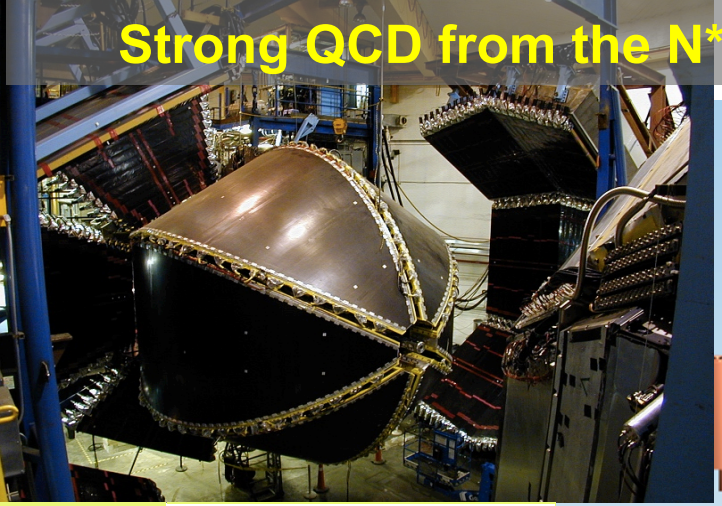
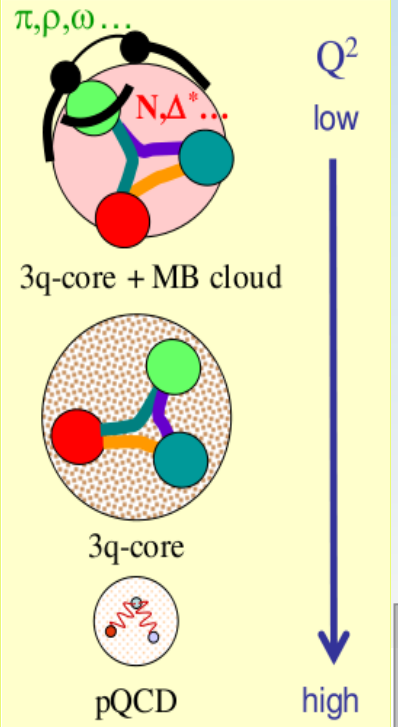
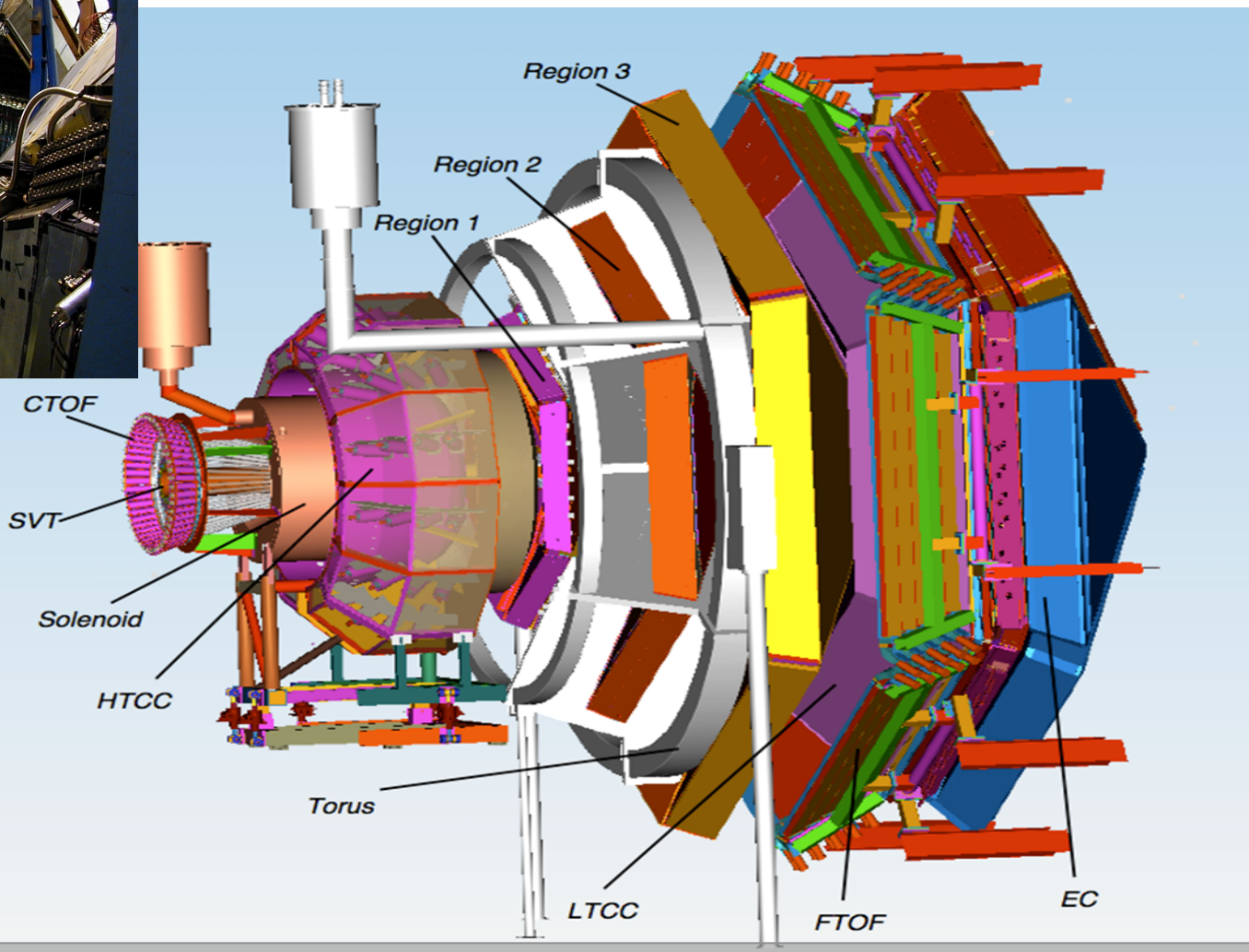
Strong QCD from the N* Structure Studies with CLAS and CLAS12







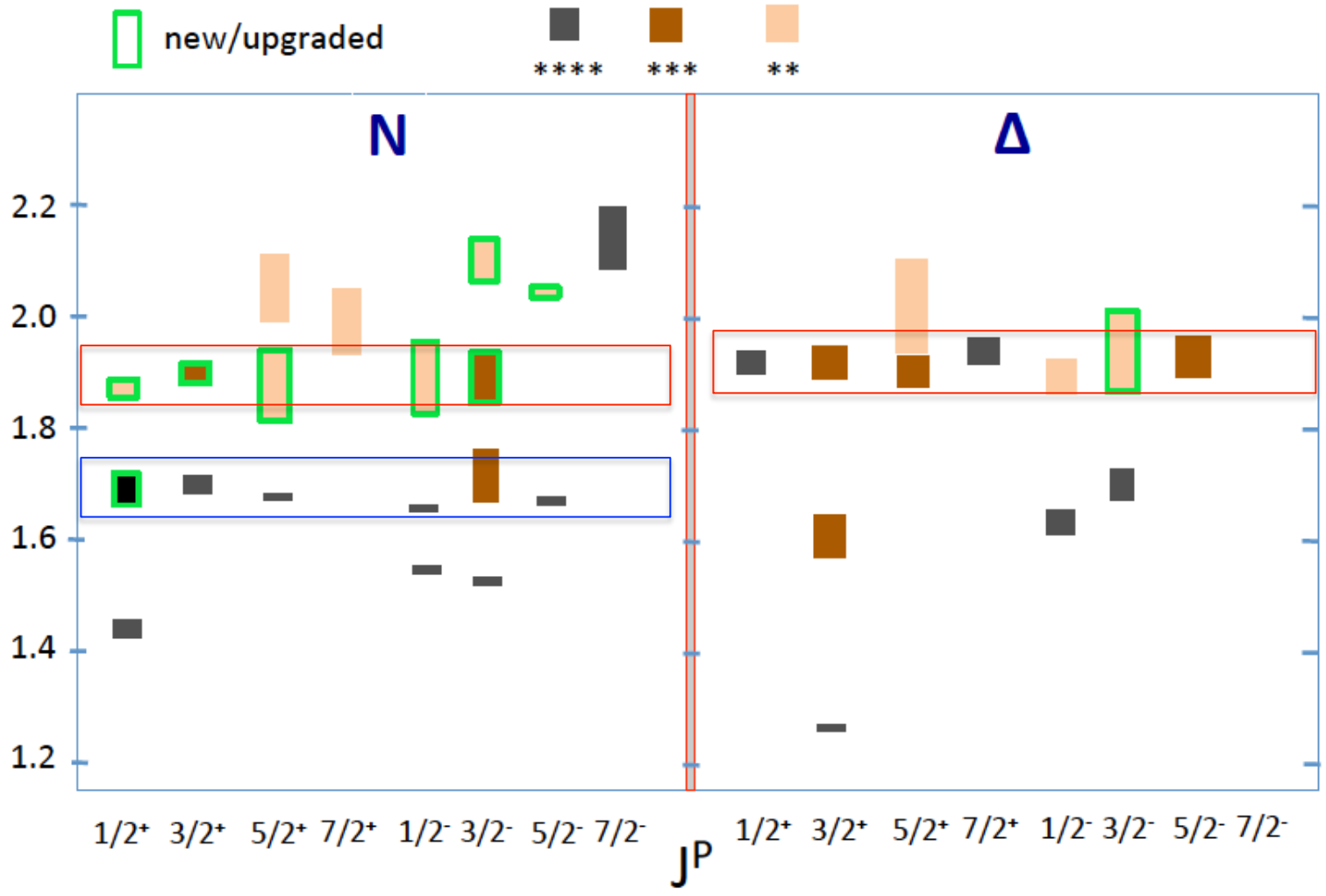
V.I. Mokeev,
Jefferson Laboratory

Skobeltsyn Nuclear Physics Institute Seminar

Outline of the Talk

- N* structure in exploration of the strong QCD dynamics.
- Current status of the results on $\gamma_{r,v}pN^*$ electrocouplings from the CLAS data
- Accessing dressed quark mass function.
- High-lying N* electrocouplings and further insight to strong QCD dynamics
- Future of the N* Program with the CLAS12.
- Request for support from SINP at MSU.

N*/Δ* spectrum in 2016



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

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

- γ_vNN* electrocouplings at photon virtualities up to 5.0 GeV^2 for most of the excited proton states through analyzing major meson electroproduction channels.
- extend knowledge on 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.

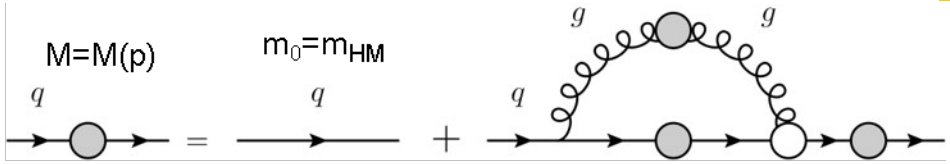
Review papers:

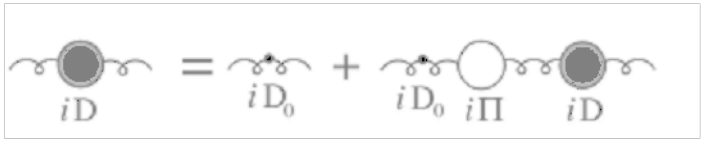
1. I.G. Aznauryan and V.D. Burkert, Prog. Part. Nucl. Phys. 67, 1 (2012).
2. I.G. Aznauryan et al., Int. J. Mod. Phys. E22,1330015 (2013).
3. V.I. Mokeev, Few Body Syst. 57, 909 (2016).
4. C.D. Roberts, J. Phys. Conf. Ser. 706, 022003 (2016).

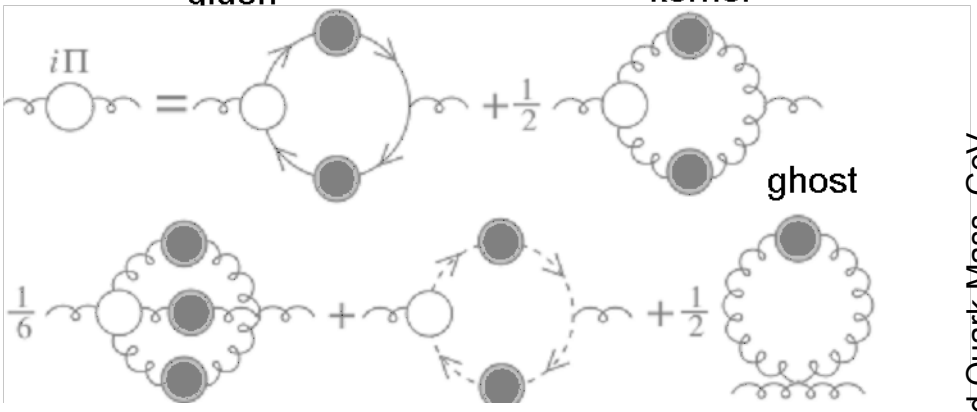
Joint activity on experimental studies of the N* structure with CLAS/CLAS12 between OEPVAYa group under Prof. B.S. Ishkhanov leadership and Hall-B at JLAB under Dr. V.D. Burkert leadership.

Excited Nucleon States and Insight to Strong QCD Dynamics

Emergence of Dressed Quarks and Gluons
C.D. Roberts, J. Phys. Conf. Ser. 706, 022003 (2016).



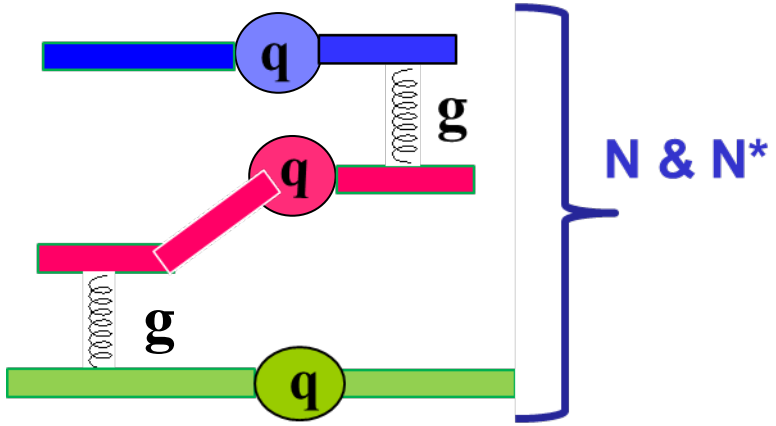




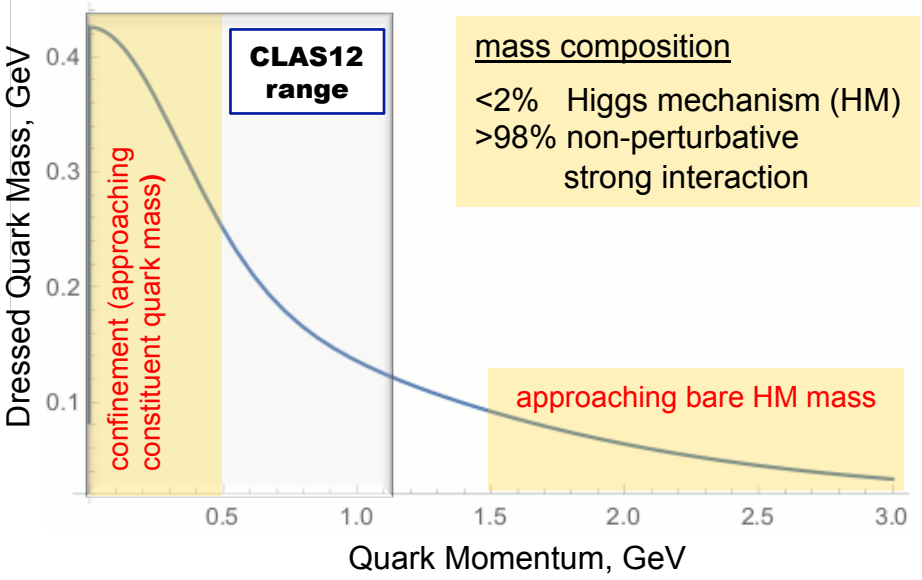
The N* structure studies address:

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

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).

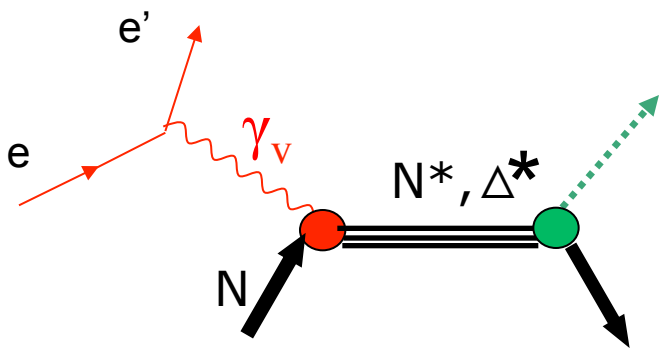


mass composition

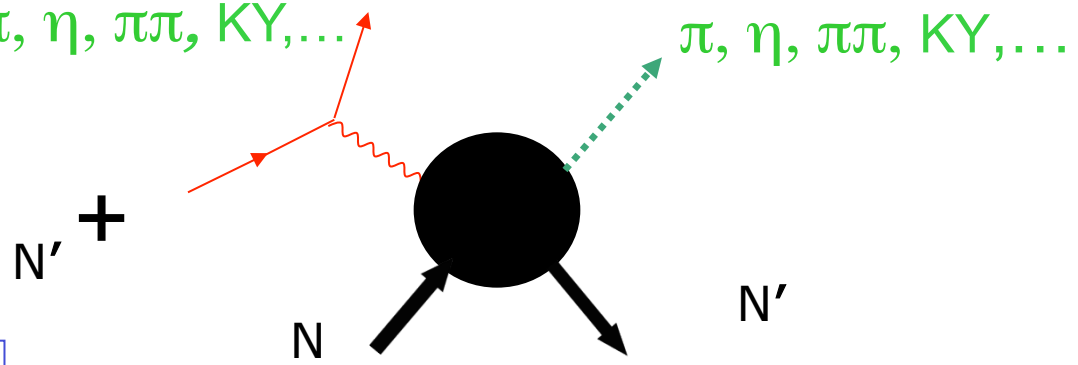
<2% Higgs mechanism (HM)
>98% non-perturbative strong interaction

Extraction of γ_vNN* Electrocouplings from the 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* electro-magnetic 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 the 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	0.2-0.6 0.5-1.5	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 asym-metries
- P^0, P' –recoil and transferred polarization of strange baryon

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. Administrated by M. Stepanov and V. Chesnokov

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

- **Analyses of different pion 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 Coll., Phys Rev. C80, 055203 (2009).

I.G. Aznauryan et al., CLAS Coll., 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 Coll., 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 Coll., 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, $\pi\pi N$, $K\Lambda$, $K\Sigma$ exclusive channels:

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

H. Kamano et al., Phys. Rev. C88, 035209 (2013).

JPAC Dispersion Relation CC approach making use of all available knowledge on exclusive meson photo- electro- and hadro-production amplitudes accounting for restrictions from unitarity and analyticity with the input from the experimental data in the CLAS Physics DB developed in OEPVAYa/Hall-B collaboration

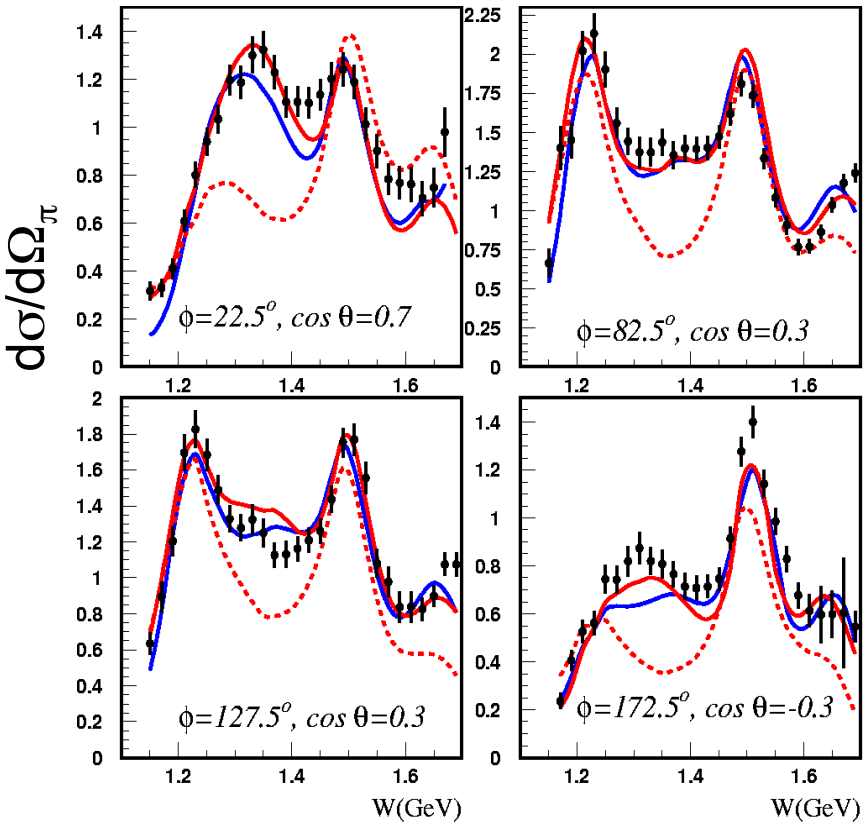
Fits to $\gamma_v p \to \pi^+ n$ Differential Cross Sections and Structure Functions

Q^2=2.05 GeV^2

DR

DR w/o P11

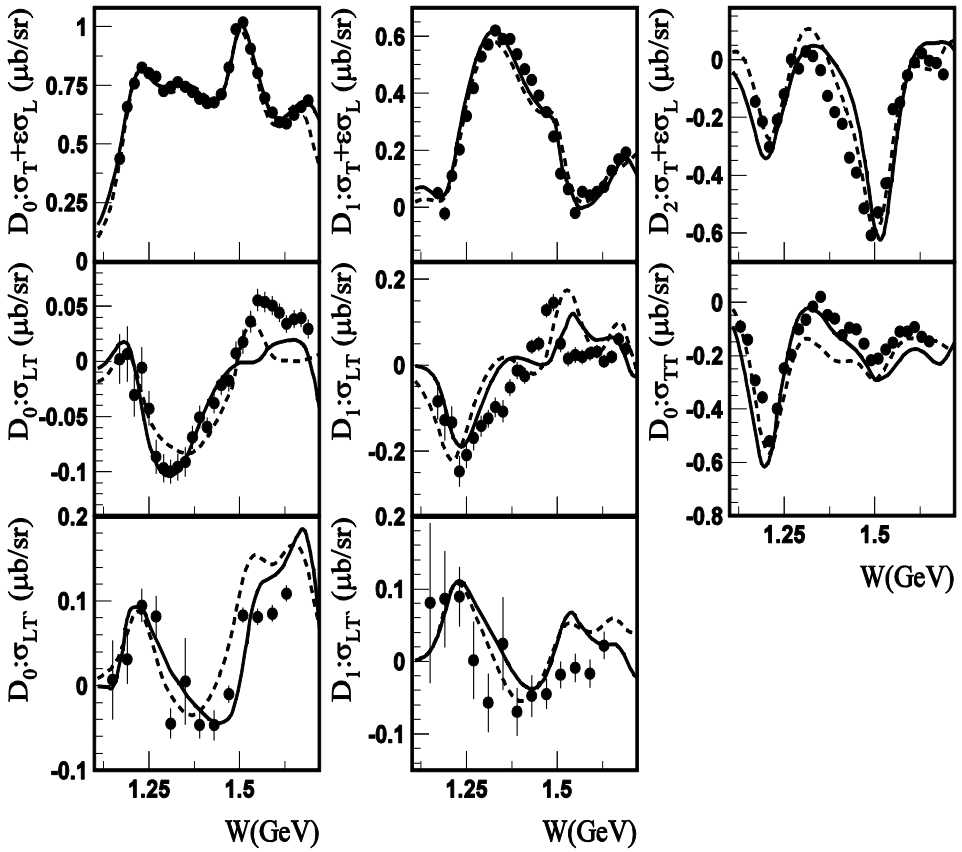
UIM



Q^2=2.44 GeV^2

DR

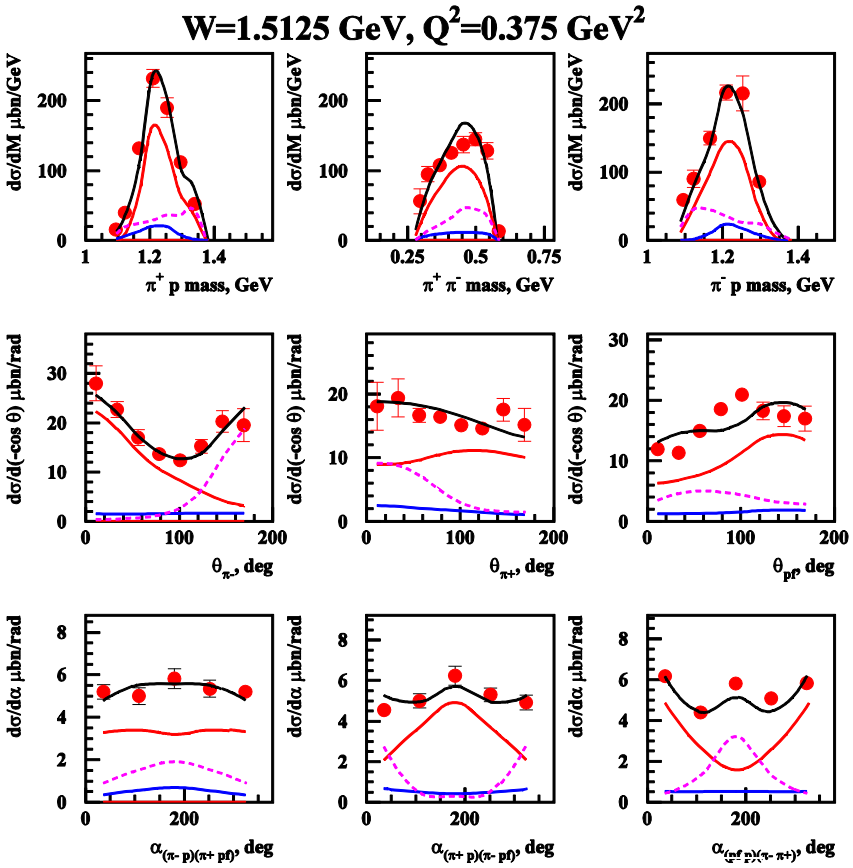
UIM



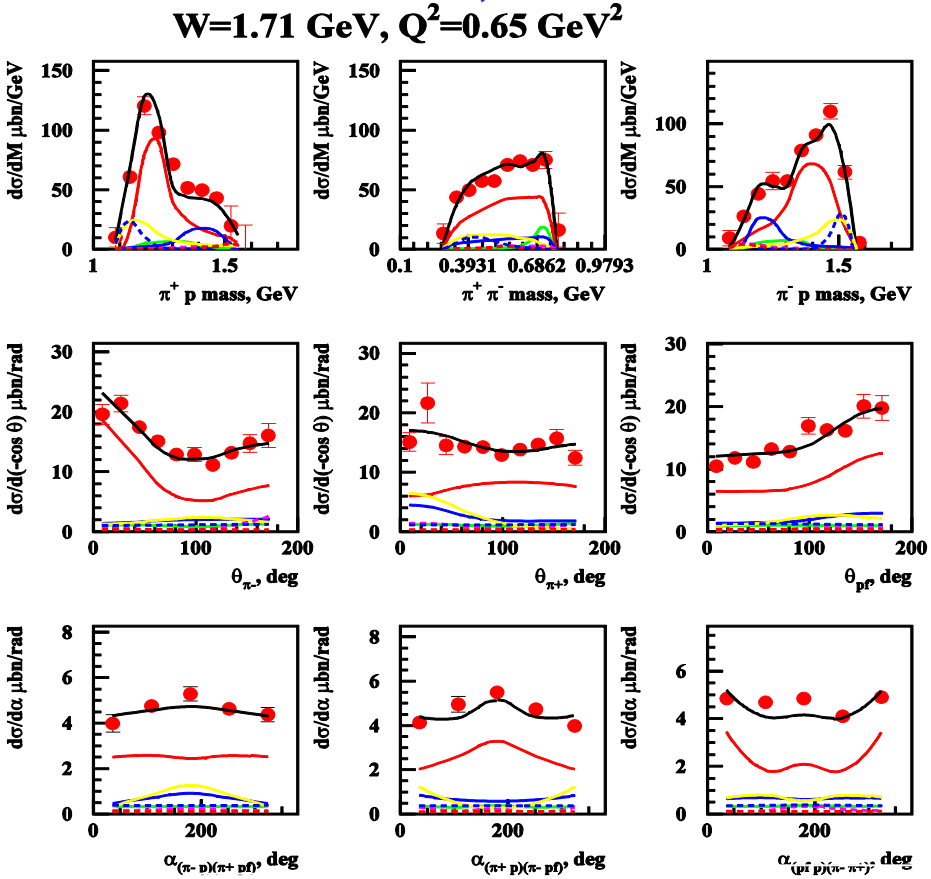
Legendre moments D_l (l=0,1,2) from various structure functions

The CLAS Data on $\pi^+\pi^-p$ Differential Cross Sections and their Fit within the Framework of Meson-Baryon Reaction Model JM

G.V.Fedotov et al, PRC 79 (2009), 015204
1.30<W<1.56 GeV; 0.2<Q^2<0.6 GeV^2



M.Ripani et al, PRL 91 (2003), 022002
1.40<W<2.30 GeV; 0.5<Q^2<1.5 GeV^2

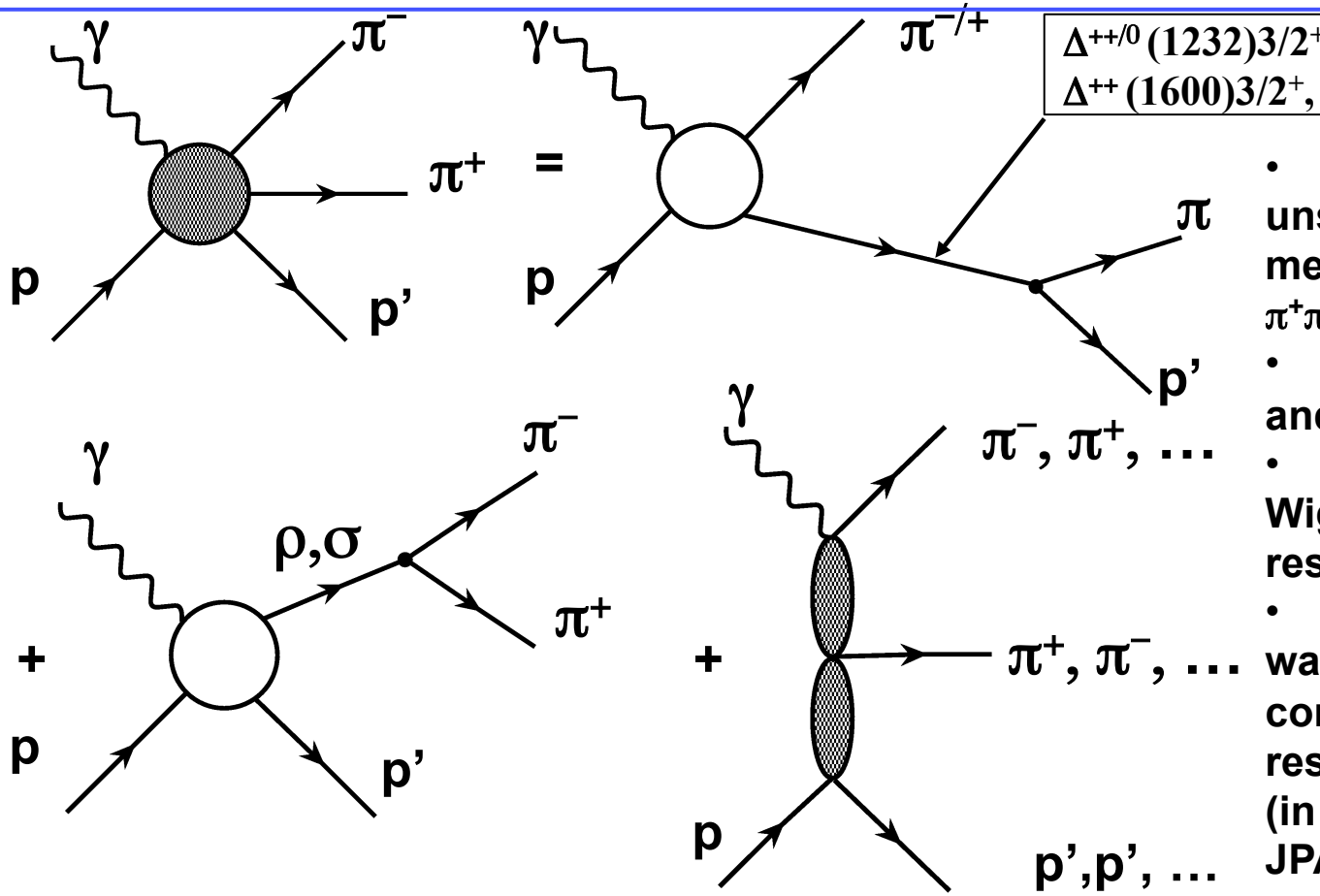


full JM calc. — $\pi^+\Delta^0$ — ρp ------- $\pi^+F^0_{15}(1680)$

$\pi^-\Delta^{++}$ ------- 2π direct — $\pi^+D^0_{13}(1520)$

JM Model Analysis of $\pi^+\pi^-$p Photo-/Electroproduction

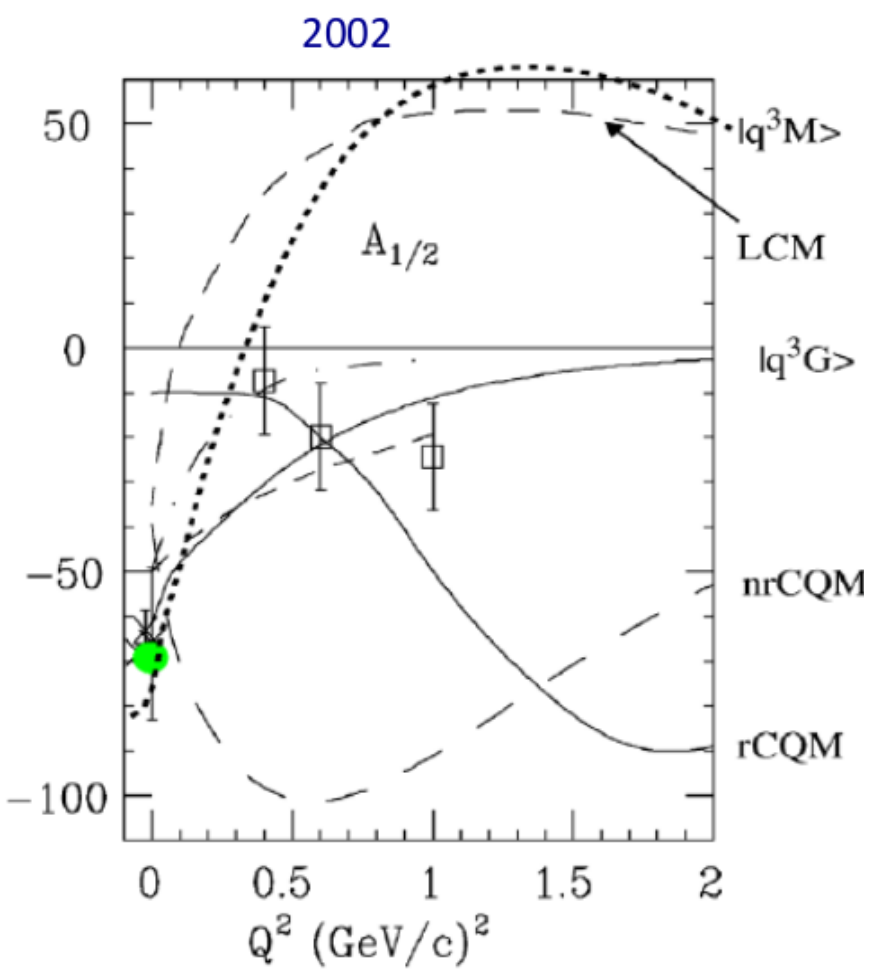
Major objectives: extraction of $\gamma_{r,v}$NN* photo-/electrocouplings and $\pi\Delta$, ρp decay widths



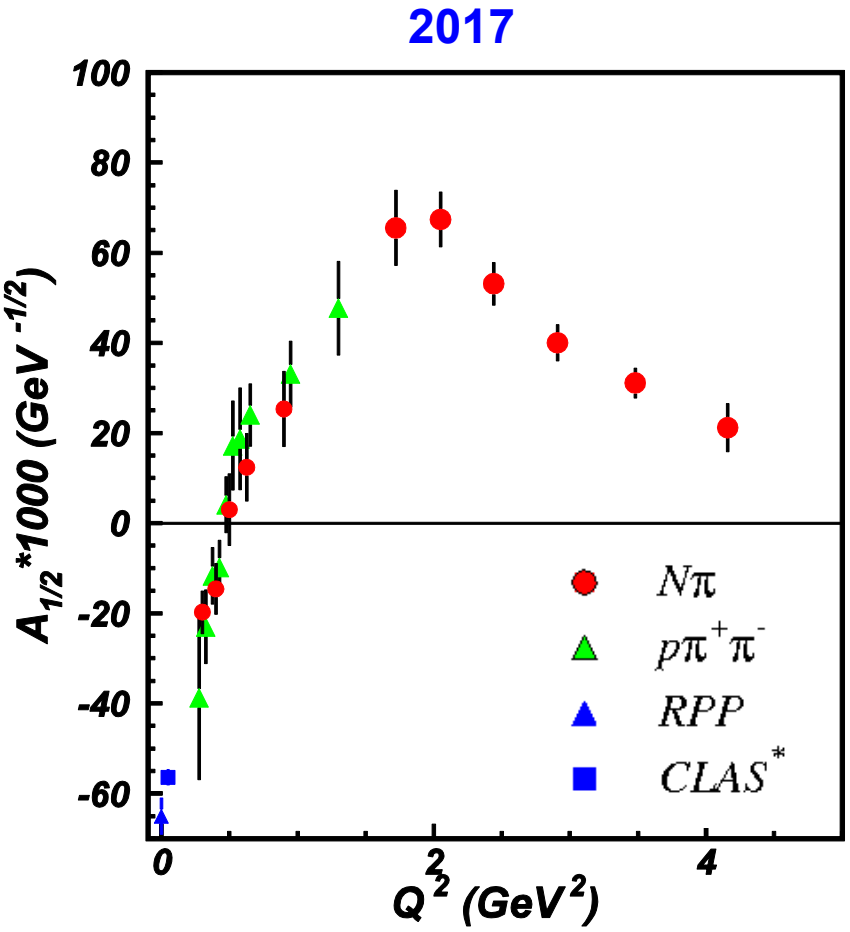
- seven channels with unstable intermediate meson/baryon and direct $\pi^+\pi^-$p production;
- N* contribute to $\pi\Delta$ and ρp channels only;
- unitarized Breit-Wigner ansatz for resonant amplitudes;
- subtraction of partial waves with resonance contributions from non-resonant amplitudes (in progress Hall-B & JPAC).
- parameterized 3-body FSI in photoproduction

1. V.I. Mokeev, V.D. Burkert et al., (CLAS Collaboration) Phys. Rev. C86, 035203 (2012).
2. V.I. Mokeev, V.D. Burkert et al., Phys. Rev. C80, 045212 (2009).

Roper Resonance in 2002 & 2017



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).

Summary of the Results on $\gamma_v pN^*$ Electrocouplings from CLAS

Exclusive meson electroproduction channels	Excited proton states	Q^2-ranges for extracted $\gamma_v NN^*$ electrocouplings, GeV^2
$\pi^0 p$, $\pi^+ n$	$\Delta(1232)3/2^+$	0.16-6.0
	$N(1440)1/2^+$,$N(1520)3/2^-$, $N(1535)1/2^-$	0.30-4.16
$\pi^+ n$	$N(1675)5/2^-$, $N(1680)5/2^+$ $N(1710)1/2^+$	1.6-4.5
ηp	$N(1535)1/2^-$	0.2-2.9
$\pi^+\pi^- p$	$N(1440)1/2^+$, $N(1520)3/2^-$	0.25-1.50
	$\Delta(1620)1/2^-$, $N(1650)1/2^-$, $N(1680)5/2^+$, $\Delta(1700)3/2^-$, $N(1720)3/2^+$, $N'(1720)3/2^+$	0.5-1.5

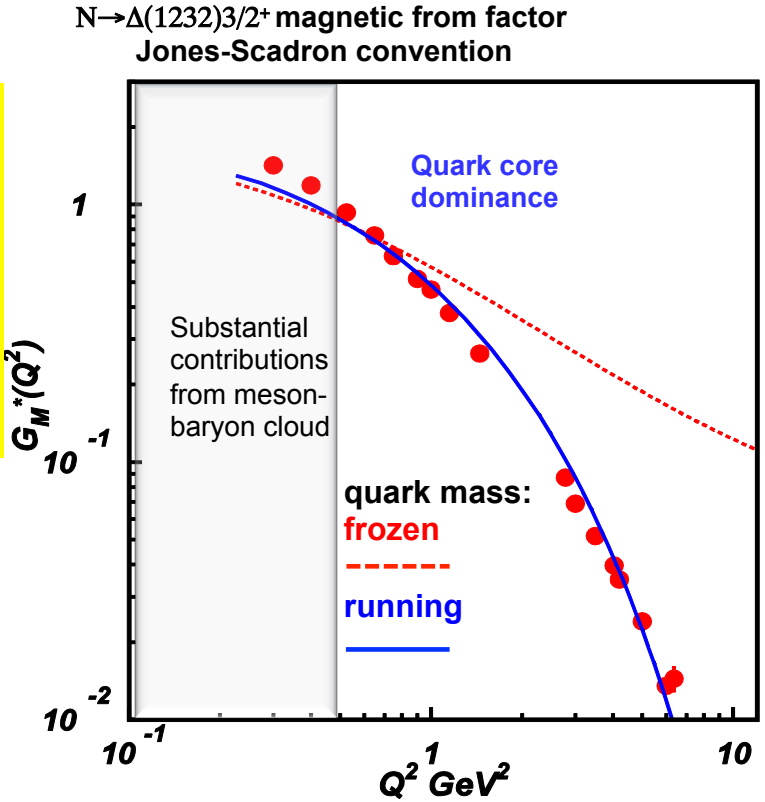
The values of resonance electrocouplings can be found in: https://userweb.jlab.org/~mokeev/resonance_electrocouplings/

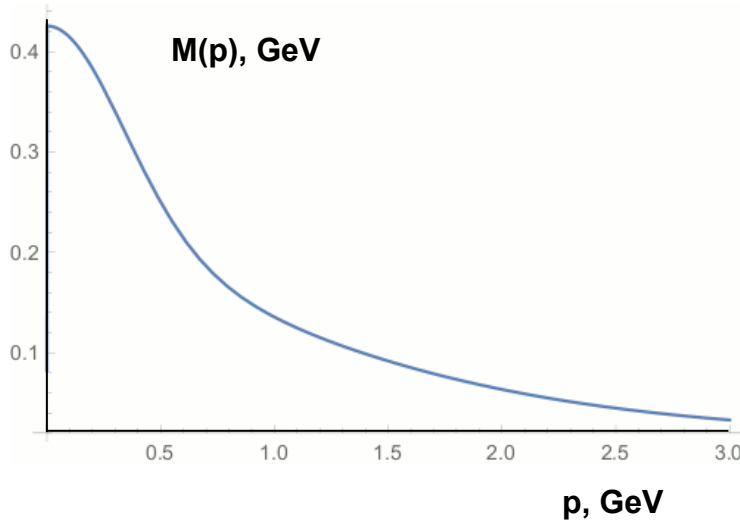
The CLAS results on $\gamma_v pN^*$ electrocouplings for the excited states in mass range up to 1.8 GeV were interpolated/extrapolated in Q^2-range up to 5.0 GeV^2. The Fortran code for computation of $\gamma_v pN^*$ electrocoupling values is available at: userweb.jlab.org/~isupov/couplings/.

Elucidating the Running Dressed Quark Mass

Dyson-Schwinger Equations (DSE):

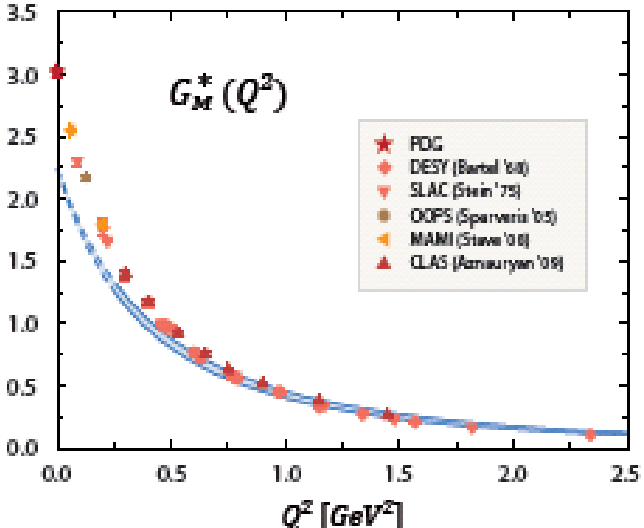
- J. Segovia et al., Phys .Rev. Lett. 115, 171801 (2015).
- J. Segovia et al., Few Body Syst. 55, 1185 (2014).

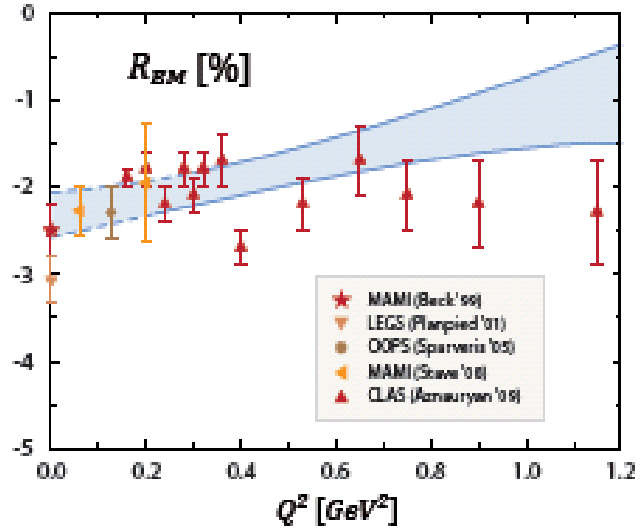




Data on Δ(1232)3/2⁺ electroexcitation from CLAS for the first time demonstrated that dressed quark mass is running with momentum.

Successful FF description with running quark mass in independent DSE studies:
G.Eichmann et al., Phys. Rev D85, 093004 (2012) over narrower range of Q^2, with simplified RL quark-gluon vertex.

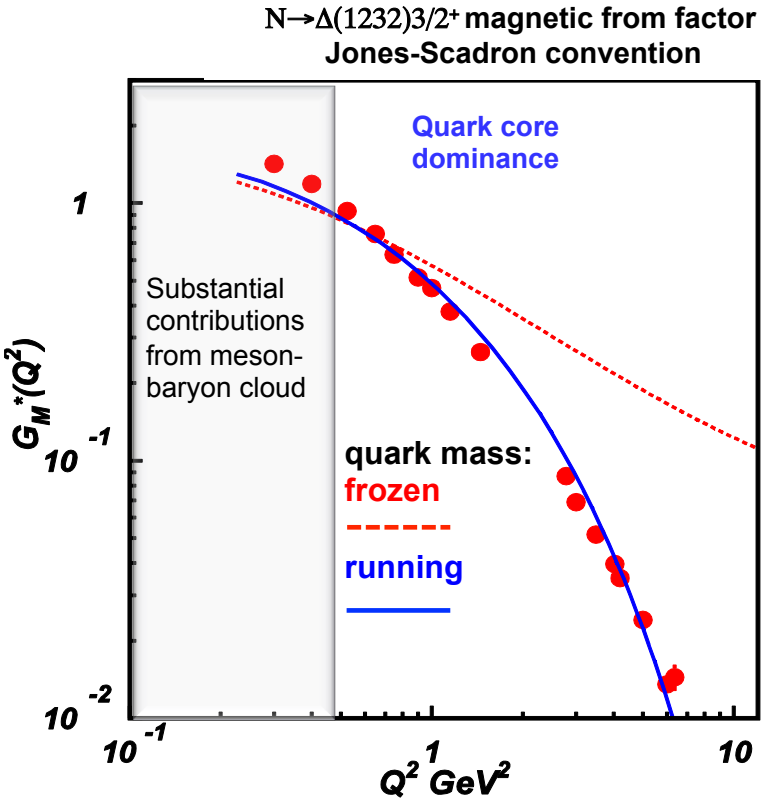


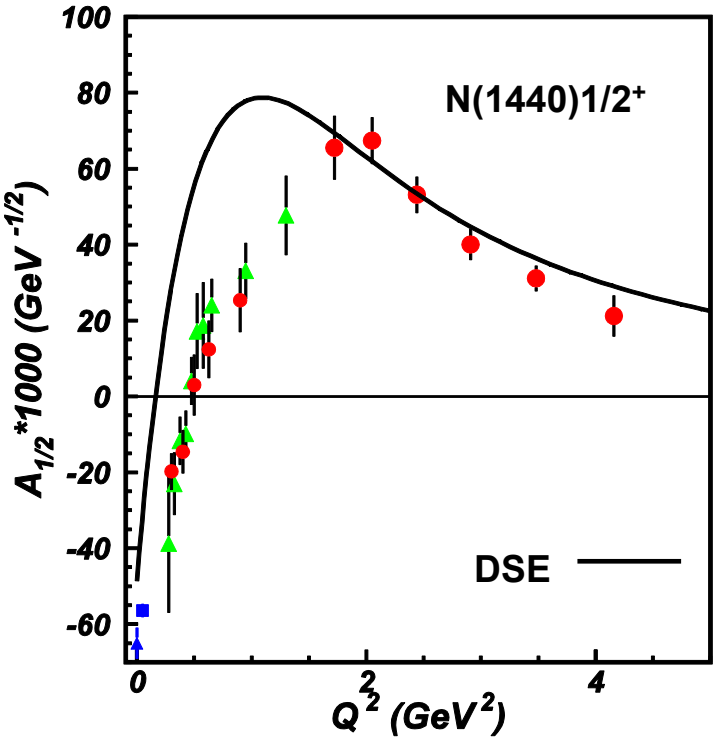


Validating the Access to the Quark Mass Function

Dyson-Schwinger Equations (DSE):

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





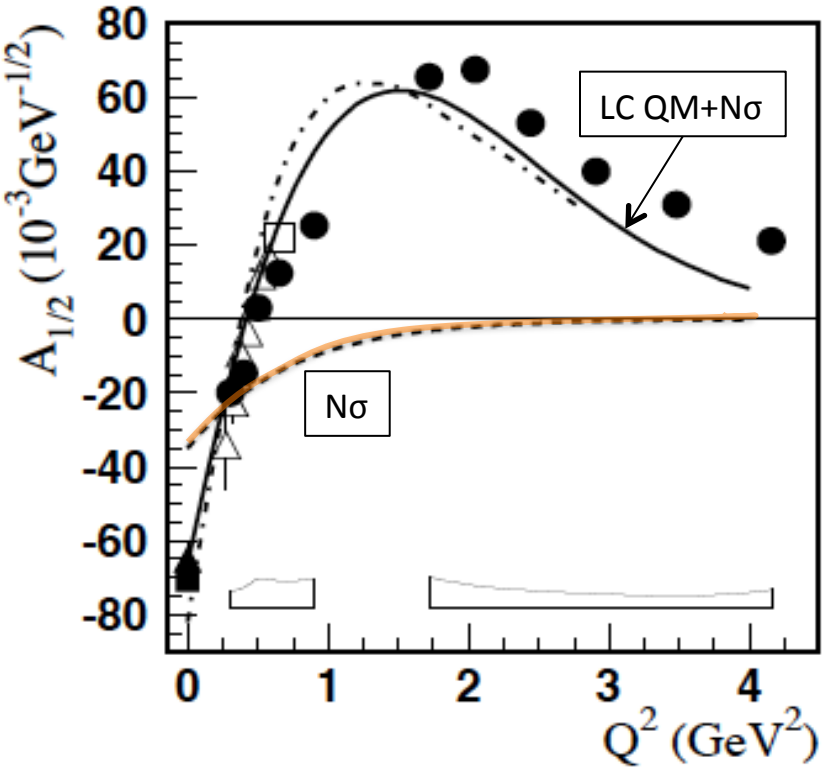
Good data description at $Q^2>2.0$ GeV^2 achieved with the same dressed quark mass function for the ground and excited nucleon states of distinctively different structure provides strong evidence for:

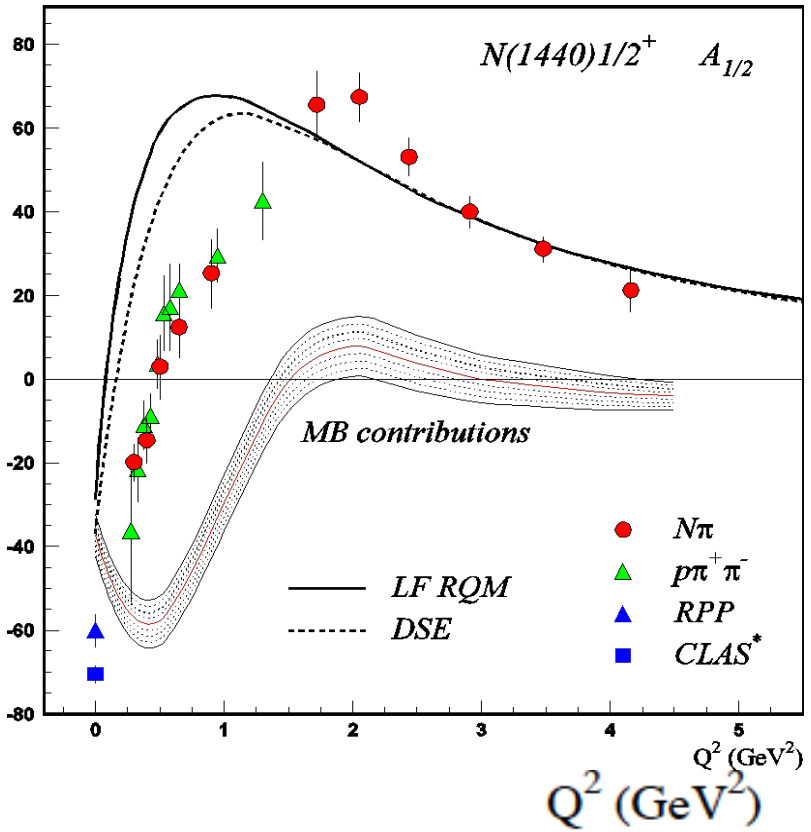
- **the relevance of dressed quarks with dynamically generated mass and structure;**
- **access to quark mass function from the data on elastic and N→N* transition form factors.**

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

Interplay between Meson-Baryon Cloud and Quark Core

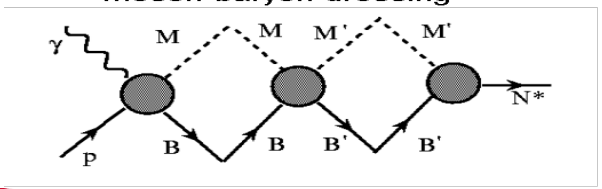
I.T. Obukhovsky et al., Phys. Rev. D89, 014032 (2012).





Accounting for the contributions from Nσ loops and quark core combined allows us to describe the data at Q^2<1.0 GeV^2

The mechanisms of the meson-baryon dressing

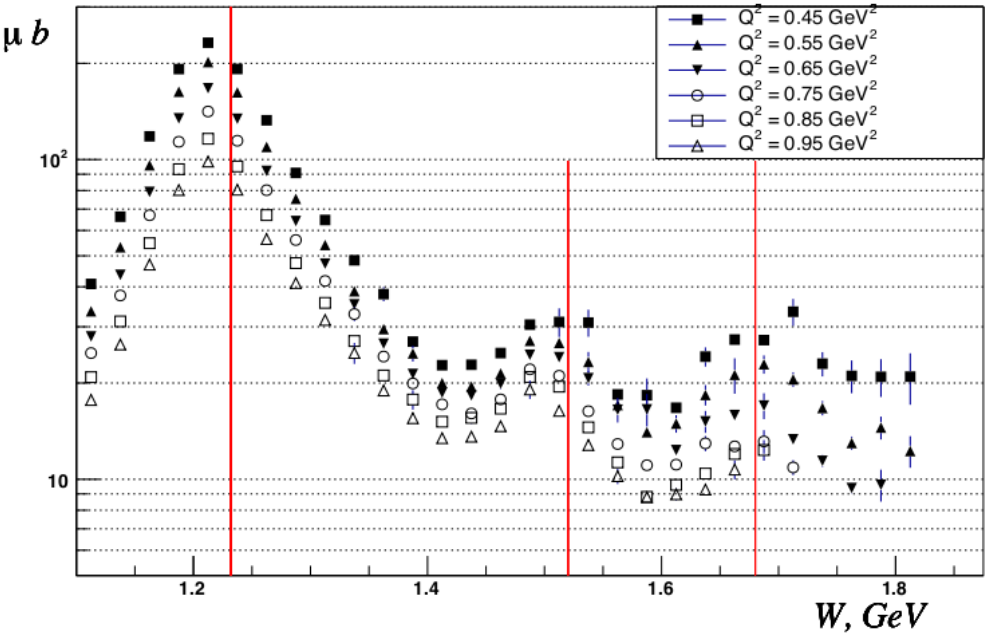


LF RQM: I.G. Aznauryan and V.D. Burkert, arXiv:1703.01751 [nucl-th] accepted by PRC

MB-cloud contribution can be obtained by subtracting the DSE estimates for quark core from the experimental results on resonance electrocouplings

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

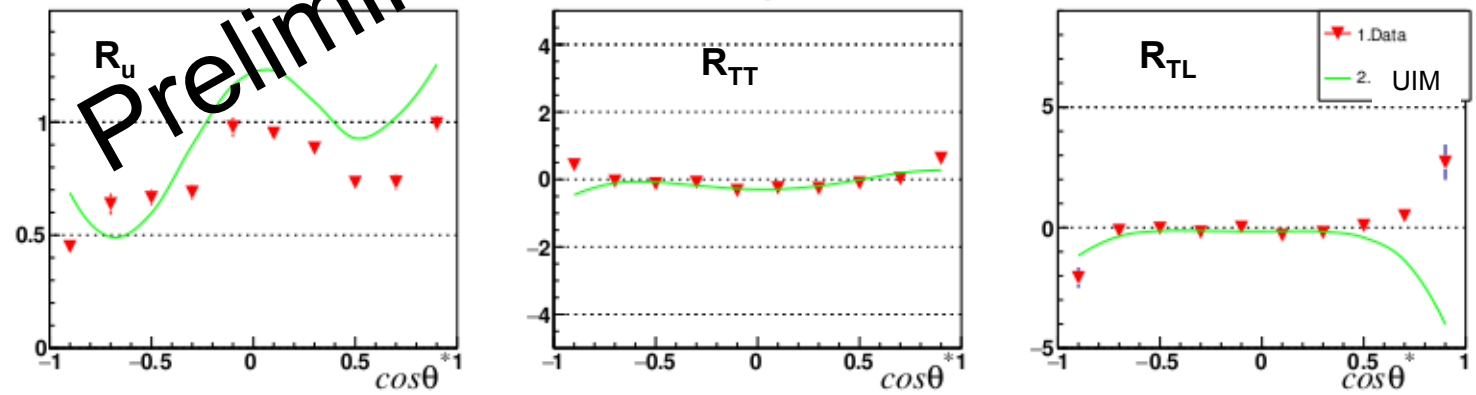
Fit of the structure functions within the framework of UIM & DR (slides #6,7) will provide electrocouplings of the resonances in mass range up to 1.8 GeV with substantial decays to the Nπ final state.

The structure functions

Preliminary

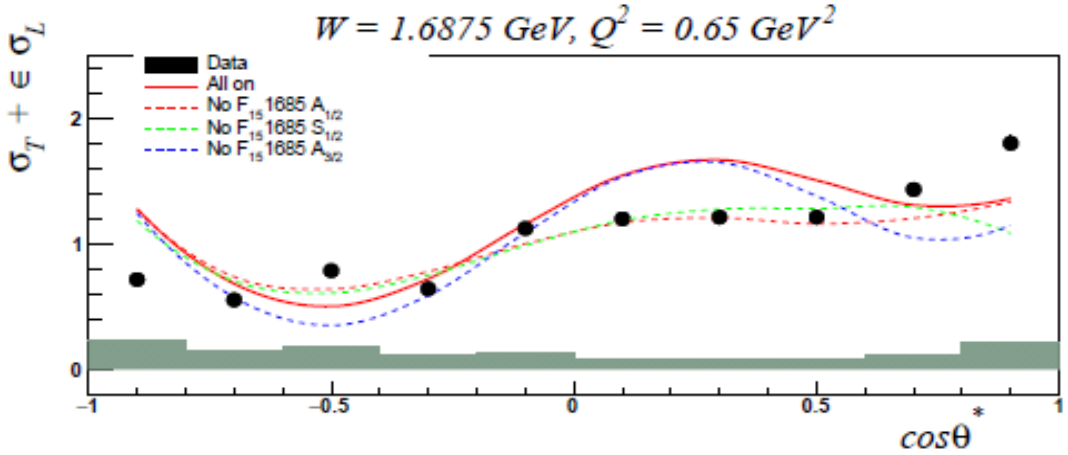
μb

$W = 1.6125, Q2 = 0.85$ **GeV^2**

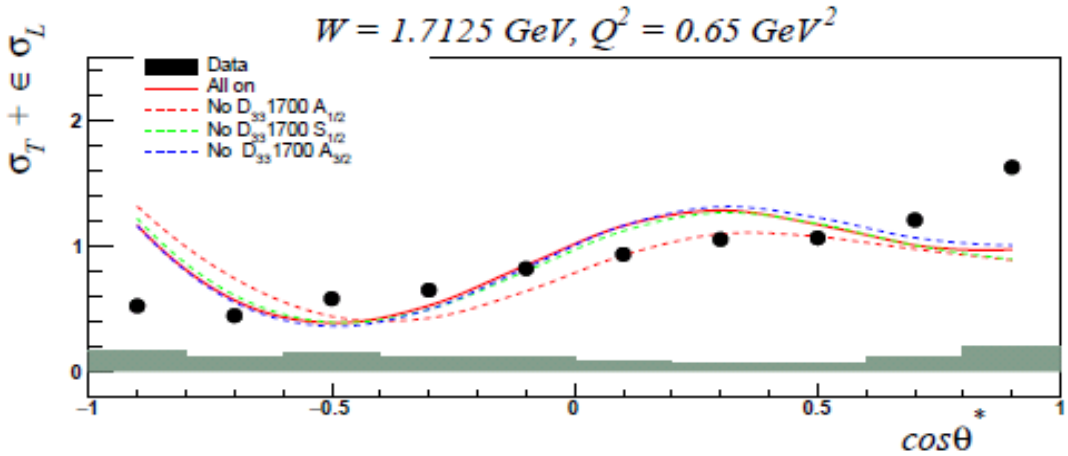


Sensitivity of the $\pi^0 p$ Electroproduction off Protons Data to Electro-couplings of the Excited Nucleon States in the 3rd Resonance Region

- **Structure functions were evaluated within the UIM (see slide # 7).**
- **$\gamma_v pN^*$ electrocouplings and hadronic decay widths were taken from previous analyses of the CLAS $N\pi$ and $\pi^+\pi^- p$ electroproduction off protons data.**
- **The data on unpolarized structure functions are compared with the UIM expectations accounting for all relevant resonances and when particular $\gamma_v pN^*$ amplitudes were switched off.**



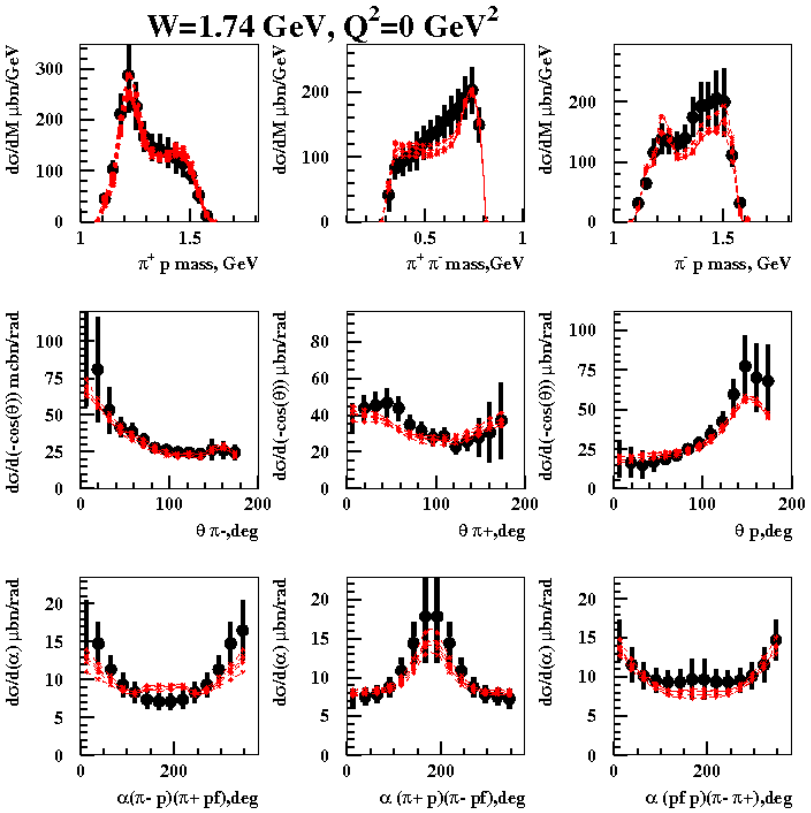
Sensitivity to electrocouplings of $N(1680)5/2^+$



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

Resonance Photocouplings from the preliminary $\pi^+\pi^-$p Photoproduction Cross Sections

Fit of the CLAS data (E.N. Golovach, MSU) achieved within the framework of the JM15:
$1.19<\chi^2/d.p.(1.6\ GeV<W<2.0\ GeV)<1.36$



Resonance	$A_{1/2}$, $GeV^{-1/2}$ *1000, JM15/RPP12	$A_{3/2}$, $GeV^{-1/2}$ *1000 JM15/RPP12
N(1650)1/2⁻	61±8 53±16	
N(1680)5/2⁺	-28±4 -15±6	128±11 133±12
N'(1720)3/2⁺	37±6 N/A	-40±7 N/A
N(1720)3/2⁺	81±12 97±3 (*)	-34±8 -39±3(*)
Δ(1620)1/2⁻	29±7 27±11	
Δ(1700)3/2⁻	87±19 104±15	87±17 85±22
Δ(1905)5/2⁺	19±8 26±11	-43±17 -45±20
Δ(1950)7/2⁺	-70±14 -76±12	-118±19 -97±10

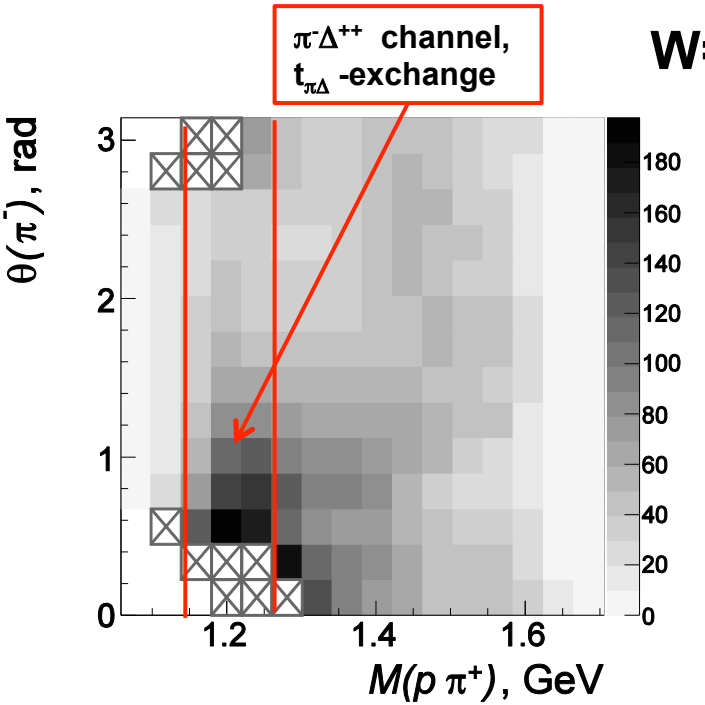
(*)M. Dugger et al., Phys. Rev. C76, 025211 (2007).

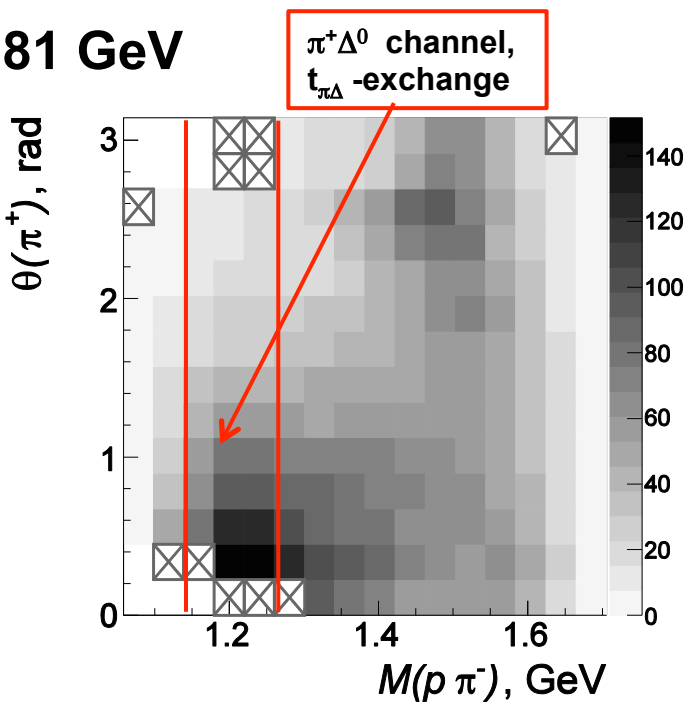
Consistent results on photocouplings of resonances with masses above 1.6 GeV from independent analyses of Nπ channels (RPP16) and $\pi^+\pi^-$p photoproduction (JM15) offer sound evidence for the reliable extraction of these fundamental quantities.

Meson-Baryon Channels with Resonant Contributions in the Preliminary Two-Fold $\pi^+\pi^-p$ Differential Photoproduction Cross Sections from the CLAS

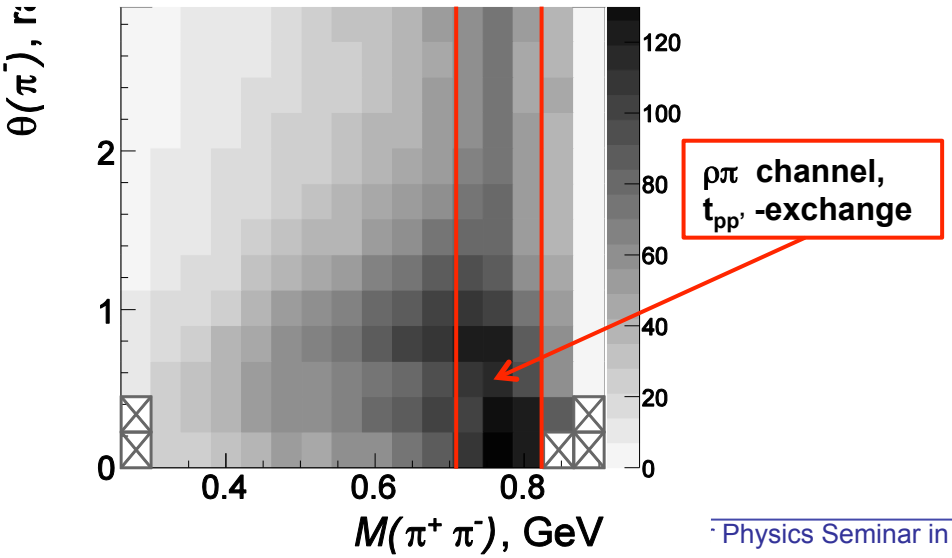
E.N. Golovach,
Moscow State Univ.

W=1.81 GeV





crossed cells with substantial contributions from the reaction phase space area of zero acceptance were taken out, but can be restored in the future physics analysis.

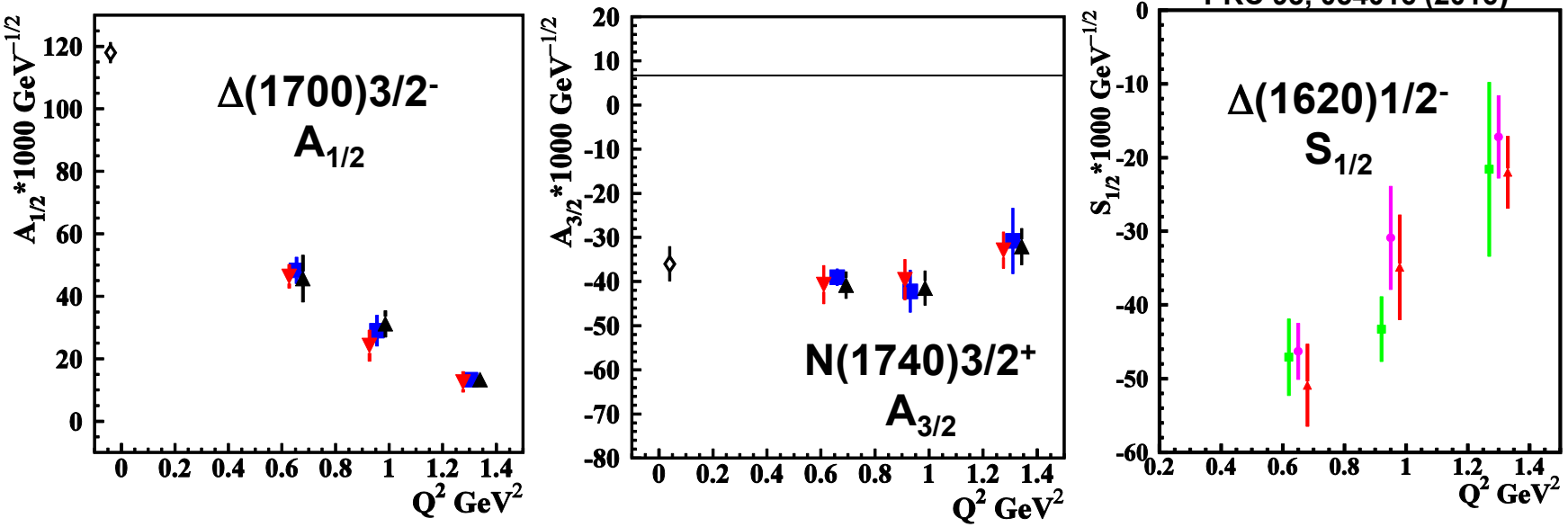


First preliminary results on nine one-fold differential and 28 two-fold differential $\pi^+\pi^-p$ photoproduction cross sections have become available from the CLAS at W from 1.6 to 2.8 GeV collected in bins of 25 MeV size over W.

Electrocouplings of the Orbital Excited Resonances from the CLAS $\pi^+\pi^-$p Electroproduction Data

V.I. Mokeev and I.G. Aznauryan., Int. J. Mod. Phys. Conf. Ser. 26. 146080 (2014)

V.I. Mokeev et al., PRC 93, 054016 (2016)



Independent fits in different W-intervals:

green: 1.51<W<1.61 GeV **red: 1.61<W<1.71 GeV** **black: 1.71<W<1.81 GeV**
magenta: 1.56<W<1.66 GeV **blue: 1.66<W<1.76 GeV**

The $\pi^+\pi^-$p electroproduction is the major source of information on electrocouplings of the $\Delta(1620)1/2^-$, $\Delta(1700)3/2^-$, and $N(1740)3/2^+$ resonances that decay preferentially to the $N\pi\pi$ final states.

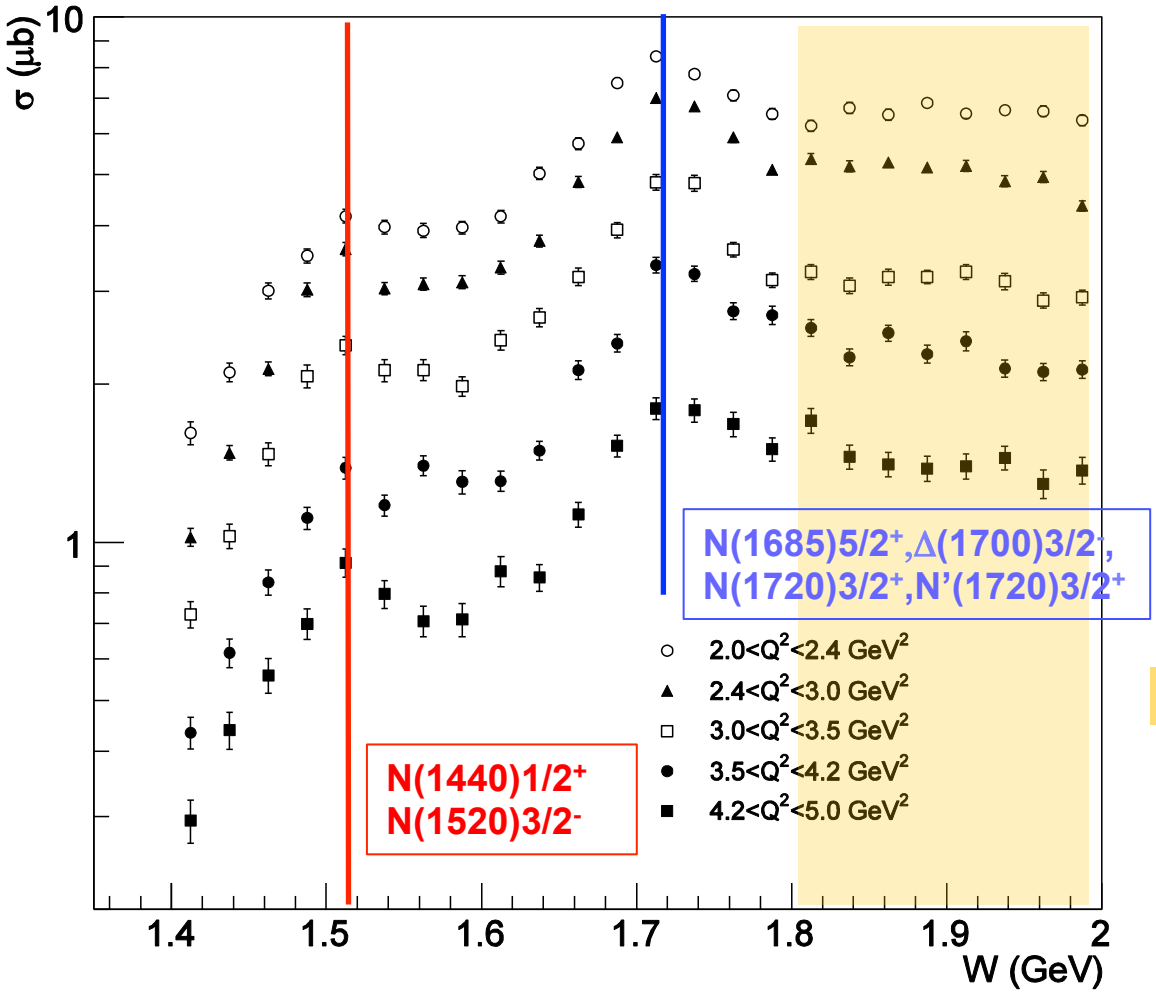
The CLAS $\pi^+\pi^-p$ Electroproduction Data at High Photon Virtualities

Fully integrated $\pi^+\pi^-p$ electroproduction cross sections off protons

1.40 GeV<W<2.00 GeV, 2.0 GeV^2<Q^2<5.0 GeV^2

E.L. Isupov, K. Hicks, MSU/Ohio Univ., and the CLAS Collaboration

arXiv:1705.01901[nucl-ex], submitted to PRC

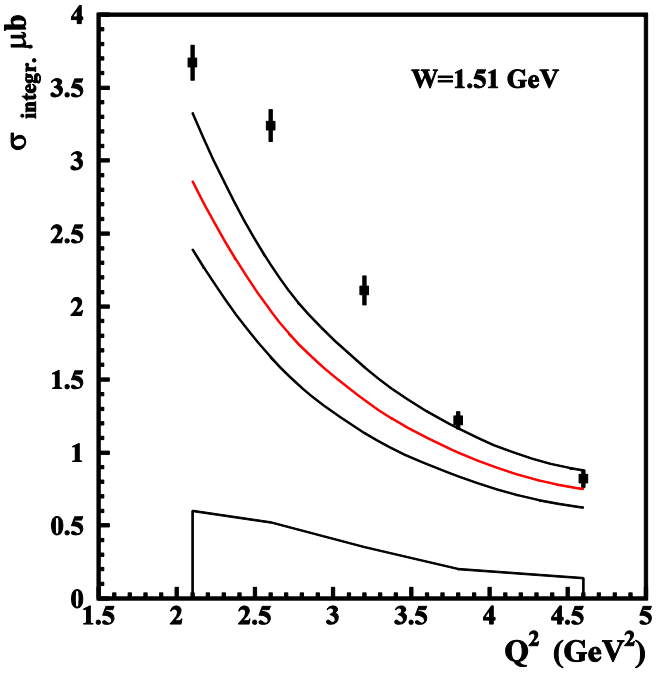


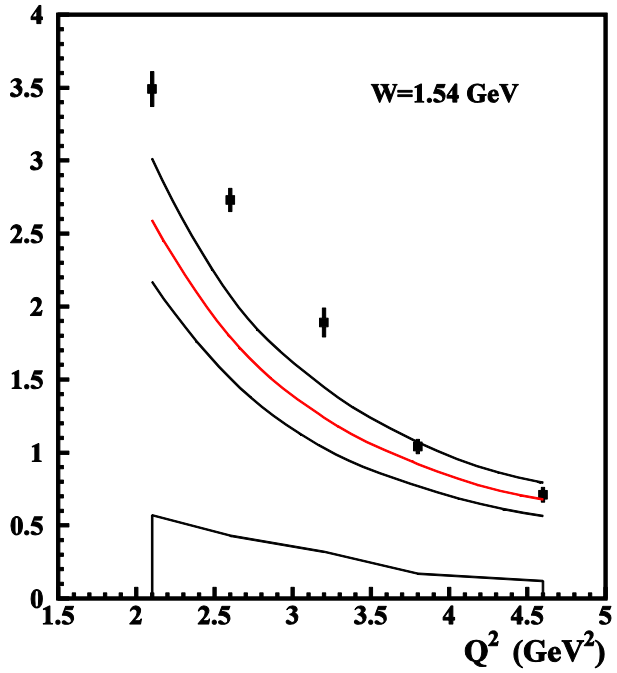
Analysis objectives:

- Extraction of $\gamma_v pN^*$ electrocouplings for most N*s in mass range up to W=2.0 GeV and 2.0< Q^2< 5.0 GeV^2 .
- Search for new baryon states through their manifestations in exclusive $\pi^+\pi^-p$ electroproduction with Q^2-independent masses and decay widths.

Mass range where the signals from new baryon states were reported, A.V. Anisovich et al., Eur. Phys. J. A48, 15 (2012).

Q^2-Evolution of the Resonant Contributions to the $\pi^+\pi^-p$ Electro-production off Protons Cross sections at 2.0 GeV^2 < Q^2 < 5.0 GeV^2





Resonant cross sections:

Central values

Uncertainty range

Error bars show the stat. uncertainty

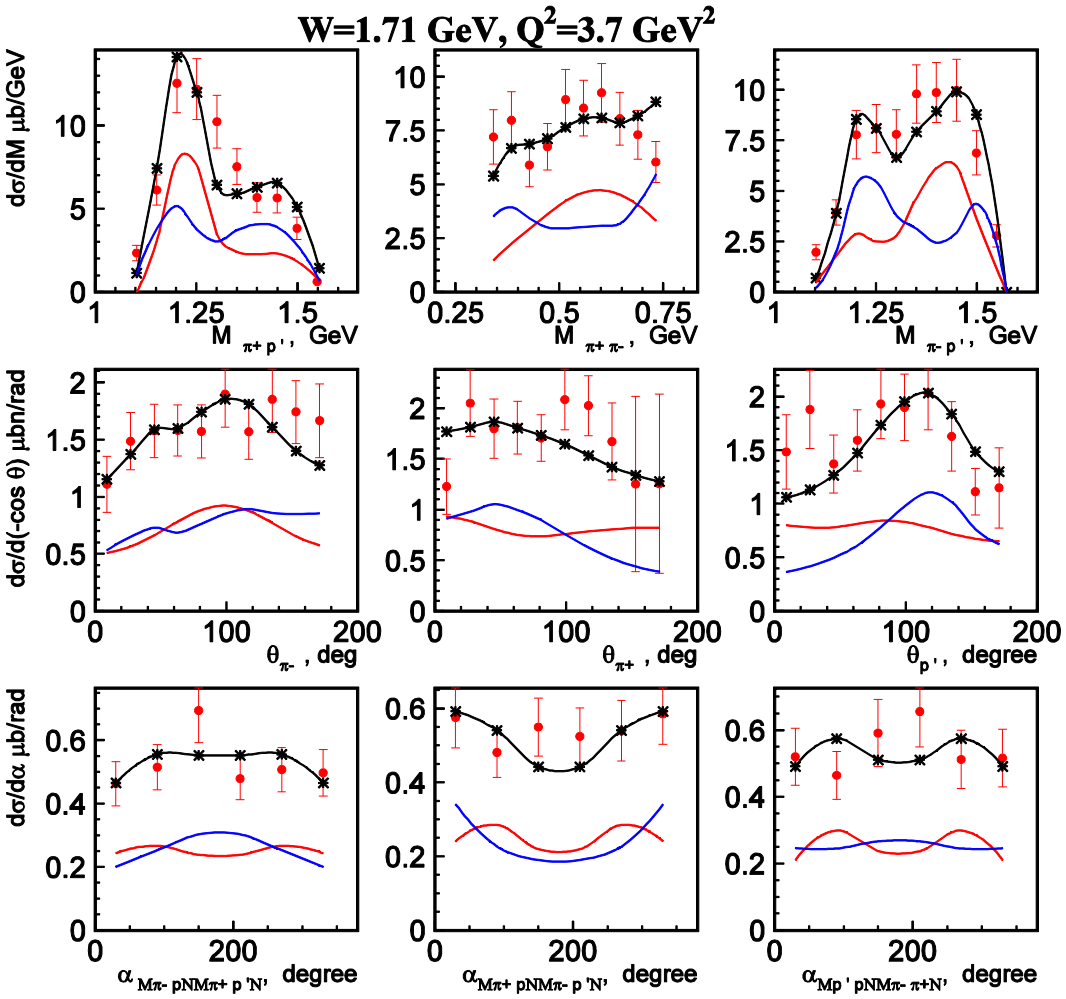
Bands on the bottom are the data syst. uncertainties

- **Resonant contributions were computed within the framework of unitarized Breit-Wigner ansatz successfully used for extraction of the resonance electrocouplings.**

- **$\gamma_v pN^*$ electrocouplings and $\pi\Delta$ and ρp decay widths were taken from the CLAS results (https://userweb.jlab.org/~mokeev/resonance_electrocouplings/, https://www.jlab.org/Hall-B, https:// secure/e1/~isupov/couplings/section1.html and references therein).**

Growth of the relative resonant contributions with Q^2 suggests good prospects for extraction of $\gamma_v pN^*$ electrocouplings in the entire range of 2.0 GeV^2<Q^2<5.0 GeV^2 .

Description of the Differential $\gamma_v p \to \pi^+\pi^- p$ Cross Sections at $2.0\ GeV^2 < Q^2 < 5.0\ GeV^2$ within the Updated JM17 Model



JM17 model;

- **no new mechanisms in comparison with JM15 (slide #9).**
- **modifications for the non-resonant amplitudes of the $\pi\Delta$, ρp, and $\pi^+N(1680)5/2^+$ meson-baryon channels.**

Resonant & non-resonant contributions from JM17 model:

- **Full**
- **Resonant contribution**
- **Non-resonant contribution**

- **Good data description at $1.4\ GeV < W < 2.0\ GeV$ and $2.0\ GeV^2 < Q^2 < 4.2\ GeV^2$ was achieved with χ^2/ d.p. < 1.4.**
- **The JM17 model is ready to determine $\gamma_v pN^*$ electrocouplings for most N^* from $\gamma_v p \to \pi^+\pi^- p$ channel for the first time.**

Strong QCD Dynamics from the Experimental Results on High-Lying $\gamma_v pN^*$ Electrocouplings

- $\gamma_v pN^*$ electrocouplings of all prominent nucleon resonances in mass range $M_{N^*}<2.0$ GeV and at $0.3<Q^2<5.0$ GeV^2 will be determined from independent analyses of $N\pi$, $N\pi\pi$, channels measured with CLAS.

- The information on the structure of orbitally excited N* with total orbital momenta of dressed quarks L=1 and L=2 will become available for the first time.

- DSE evaluations of the $[70,1^-]$, $[56,2^+]$ $SU_{sf}(6)$-multiplet electrocouplings will extend the access to the strong QCD dynamics allowing us to address:
  - a) environmental sensitivity or universality of the quark mass function to orbital excitations of three dressed quarks;
  - b) complexity of quark-gluon vertex dressing beyond rainbow-ladder truncation;
  - c) first studies of pseudoscalar and vector di-quark correlations;
  - d) shed light on DCSB and its evolution with distance from studies of chiral partner structure $\Delta(1232)3/2^+$ vs $\Delta(1700)3/2^-$ as the first step.

Technical Scope

Forward Detector (FD)

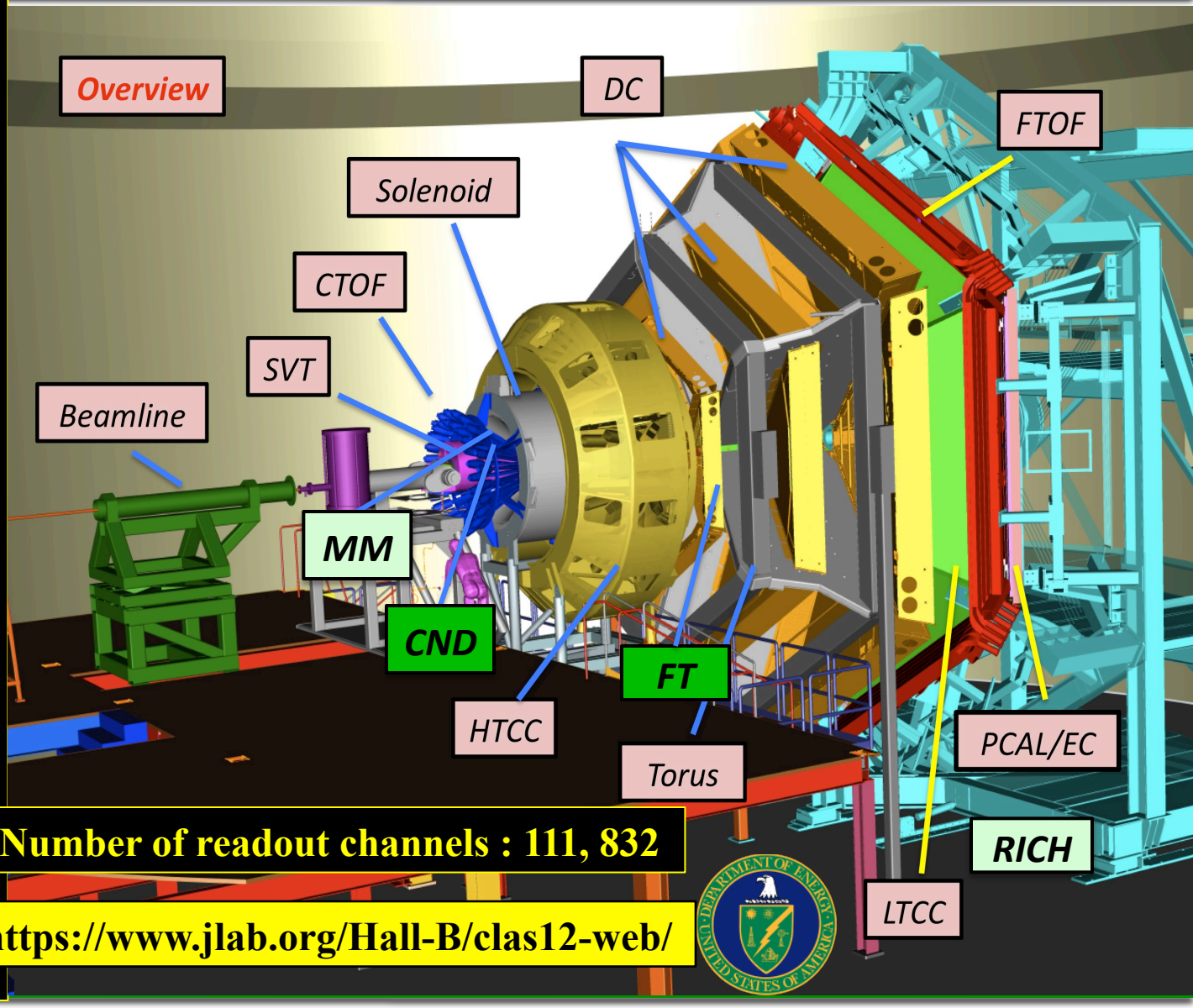
- TORUS magnet
- HT Cherenkov Counter
- Drift chamber system
- LT Cherenkov Counter
- Forward ToF System
- Pre-shower calorimeter
- E.M. calorimeter
- Forward Tagger
- RICH detector

Central Detector (CD)

- Solenoid magnet (1)
- Silicon Vertex Tracker
- Central Time-of-Flight
- Central Neutron Det.
- MicroMegas

Beamline

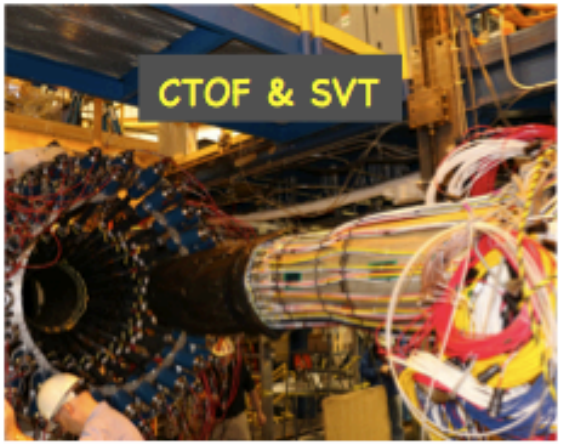
- Photon Tagger
- Shielding
- Cryo Target
- Moller polarimeter
- Polarized Targets

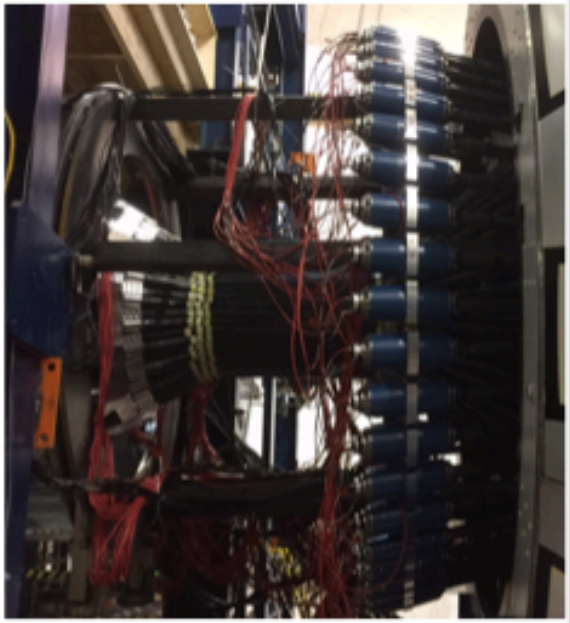


Number of readout channels : 111, 832

https://www.jlab.org/Hall-B/clas12-web/

Equipment for KPP





Forward Tagger (FT)

Detect electrons at small angle to perform quasi-real photo-production experiments.

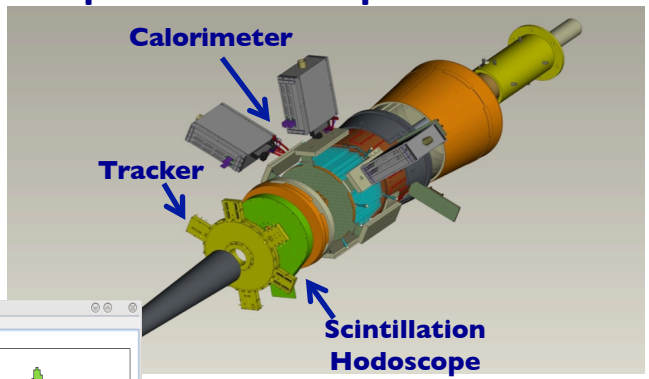
Calorimeter: electron energy/momentum

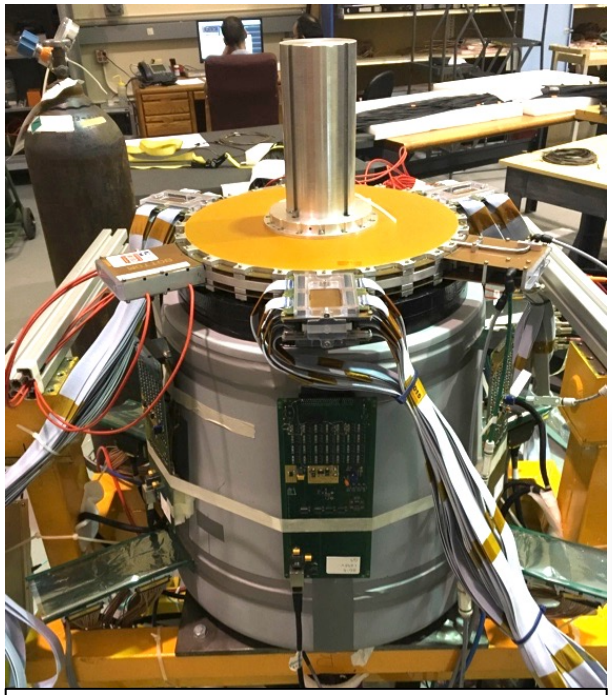
Photon energy (ν=E-E'), Polarization $\varepsilon^{-1} \approx 1 + \nu^2/2EE'$

$PbWO_4$ crystals with APD/SiPM readout

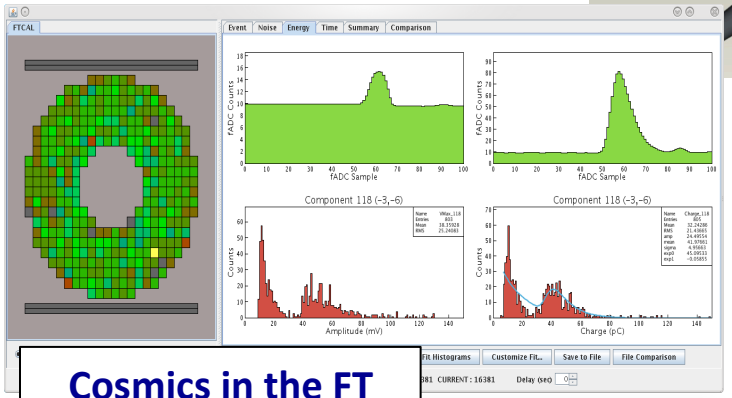
Scintillation Hodoscope: veto for photons, Scintillator tiles with WLS

Tracker: electron angles, polarization plane, MicroMegas detectors

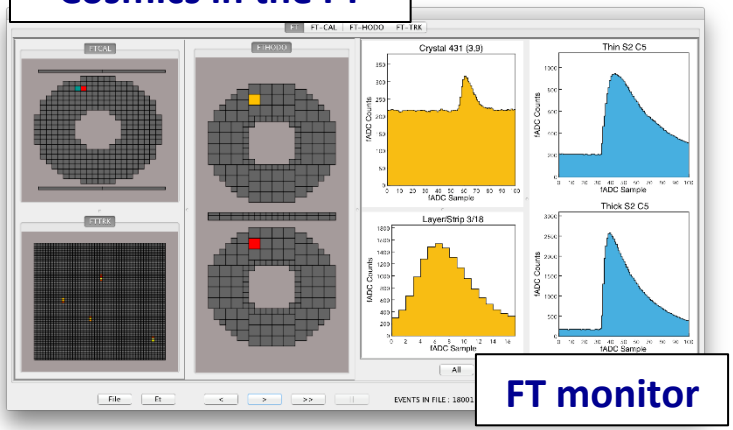




FT-Cal+FT-Hodo+FT-Trck cosmic test at JLab



Cosmics in the FT



FT monitor

- First calibration w/ cosmics
- Hardware interlocks in preparation by DSG
- FT-Cal final assembly in May
- FT checkout in June (in EEL)
- Installation in CLAS12 in July
- Implementation of R/O in CLAS12 DAQ in summer
- FT-Cal + FT-Hodo reconstruction implemented in COATJAVA3.0.
- FT-Trck in progress

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. Carman, et al.)*

Approved by PAC44

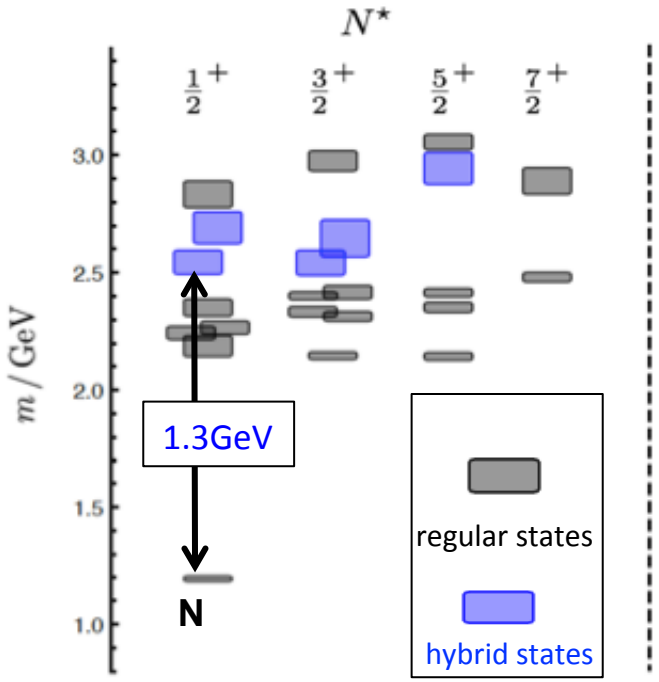
Run Group conditions:
E_b = 6.6 GeV, 50 days
E_b = 8.8 GeV, 50 days

- 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?

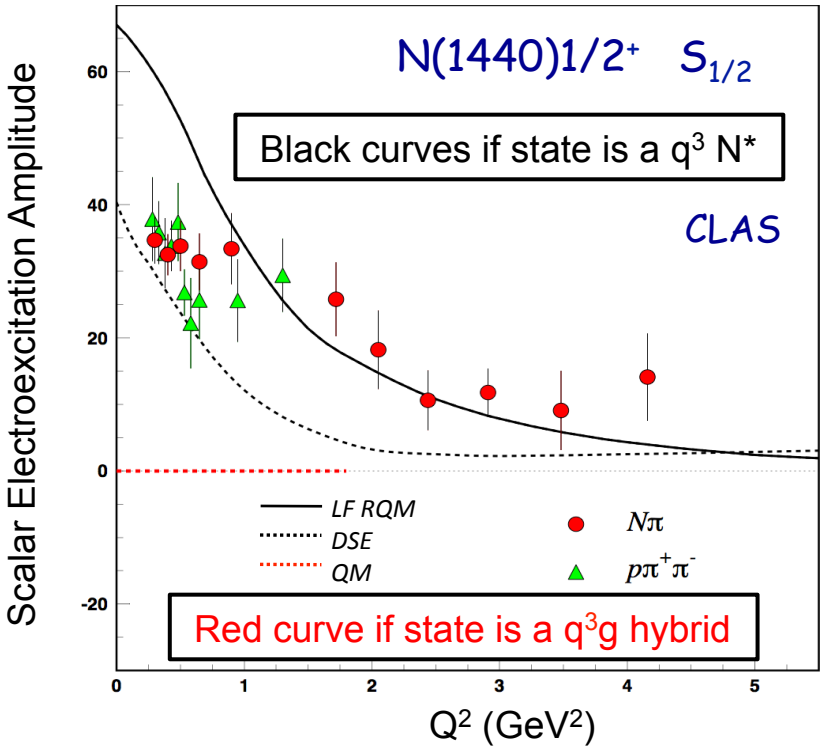
Predictions of the N* spectrum from QCD show both regular q^3 *and* hybrid q^3g states



JLab LQCD group results

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

The only way to establish the nature of a baryon state as q^3 or q^3g is from the Q^2 evolution of its electroexcitation amplitudes



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!

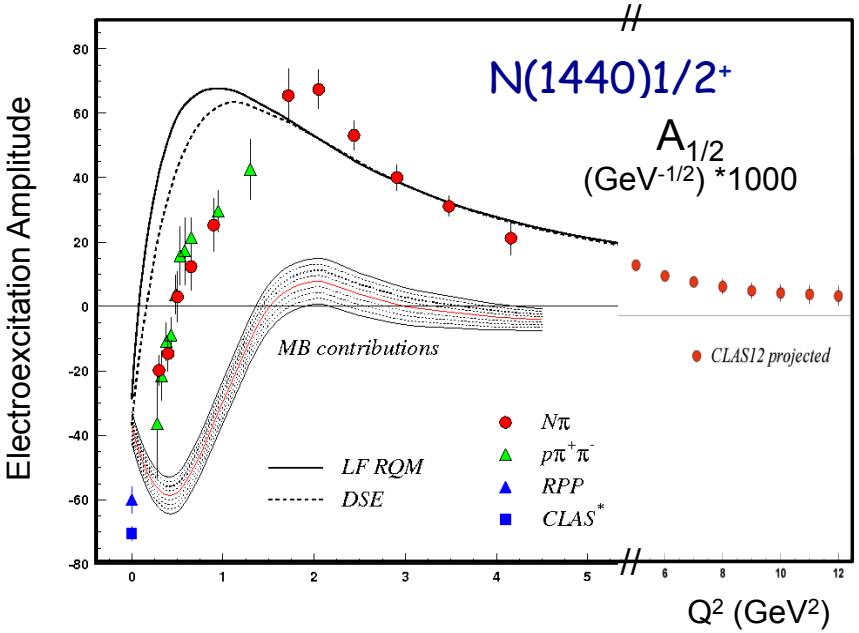
Emergence of Hadron Mass and Quark-Gluon Confinement

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

How is >98% of visible mass generated,?

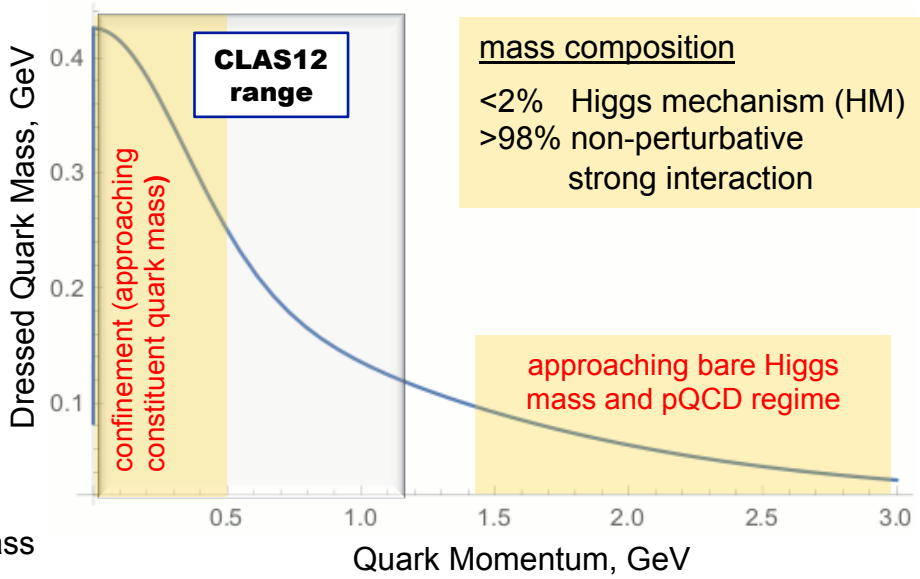
How confinement emerges from QCD and how it is related to DCSB?

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 versus theory expectations with running quark mass

Access to the dressed quark mass function



mass composition

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

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.**

- **<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 DSE theory (C.D. Roberts) and the experimental studies of $\gamma_v pN^*$ electrpocouplings in Hall-B at JLab (V.D. Burkert) have revealed the capability for reliable access to quark mass function for the first time.
  c) resonance electrocouplings from CLAS revealed the N* structure as a complex interplay between inner core of three dressed quarks and outer MB-cloud.

- **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 $N\pi$ and $\pi^+\pi^-p$ electroproduction in the near term future.**

- **Future analyses the CLAS results on electrocouplings of orbital-excited resonances within the QCD-based framework will extend insight to the strong QCD dynamics addressing:**
  a) the environmental sensitivity or universality of dressed quark mass function,
  b) complexity of the dressed quark-gluon vertex and qq-interaction kernel,
  c) shed light on the DCSB manifestation in the structure of chiral partners $\Delta(1232)\ 3/2^+$ and $\Delta(1700)3/2^-$.

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 $N\pi$, $\pi^+\pi^-p$, and KY 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 quark-gluon confinement.

- **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, phenomenology, and the QCD-based hadron structure theory.**

Request for Support of the N* Studies with the CLAS12 from SINP at MSU

- **Development of the procedures for extraction of cross sections and polarization asymmetries from the future data with the CLAS12 at W<2.5 GeV in exclusive channels $\pi^+\pi^-p$ at 0.05 GeV^2 <Q^2< 12 GeV^2 ; $K\Lambda$, $K\Sigma$ at 2.0 GeV^2 <Q^2< 12 GeV^2 (E.N. Golovach, contact person golovach@jlab.org).**

- **Upgrade of the CLAS Physics DB in order to provide the data interface for N* parameter extraction in the multi-channel coupled channel analyses under development by the JPAC at Jefferson Lab.**

- **Reaction models for extraction of $\gamma_v pN^*$ electrocouplings at 3.0 GeV^2 <Q^2< 12 GeV^2 which incorporate quark degrees of freedom .**

- **Reaction models for extraction of the $\gamma_v pN^*$ electrocouplings in exclusive KY electroproduction.**

- **Predictions on Q^2-evolution of the hybrid baryon electrocouplings.**

- **Evaluation of $\gamma_v pN^*$ electrocouplings for orbital-excited resonances at Q^2<12 GeV^2 within different quark models**

All contributions are welcome ! (V.I. Mokeev, spokeperson for the N* Program with the CLAS12, mokeev@jlab.org)

Hall B – Run Groups

HALL B

Proposal	Physics	Contact	Rating	Days	Group	New equipment	Energy	Run Group	Target
E12-06-108	Hard exclusive electro-production of π^0, η	Stoler	B	80	139	RICH (1 sector) Forward tagger	11	A F. Sabatié	liquid H_2
E12-06-108A	Exclusive N*->KY Studies with CLAS12	Carman		(60)					
E12-06-108B	Transition Form Factor of the η' Meson with CLAS12	Kunkel		(80)					
E12-06-112	Proton's quark dynamics in SIDIS pion production	Avakian	A	60					
E12-06-112A	Semi-inclusive Λ productiuon in target fragmentation region	Mirazita		(60)					
E12-06-112B	Colinear nucleon structure at twist-3	Pisano		(60)					
E12-06-119(a)	Deeply Virtual Compton Scattering	Sabatie	A	80					
E12-09-003	Excitation of nucleon resonances at high Q^2	Gothe	B+	40					
E12-11-005	Hadron spectroscopy with forward tagger	Battaglieri	A-	119					
E12-11-005A	Photoproduction of the very strangest baryon	Guo		(120)					
E12-12-001	Timelike Compton Scatt. & J/ψ production in e+e-	Nadel-Turonski	A-	120					
E12-12-007	Exclusive φ meson electroproduction with CLAS12	Stoler, Weiss	B+	60					
E12-07-104	Neutron magnetic form factor	Gilfoyle	A-	30	90	Neutron detector RICH (1 sector) Forward tagger	11	B K. Hafidi	liquid D_2 target
E12-09-007(a)	Study of partonic distributions in SIDIS kaon production	Hafidi	A-	30					
E12-09-008	Boer-Mulders asymmetry in K SIDIS w/ H and D targets	Contalbrigo	A-	56					
E12-09-008A	Hadron production in target fragmentation region	Mirazita		(60)					
E12-09-008B	Colinear nucleon structuer at twist-3	Pisano		(60)					
E12-11-003	DVCS on neutron target	Niccolai	A	90					
E12-11-003A	In medium structure functions, SRC, and the EMC effect	Hen		(90)					
Beam time partial sum				**765 (1355)**	**229**				

Experiment ending with A or B are run group experiments approved by the CLAS collaboration. They are running parallel to the experiments with same experiment number. (★) Experiments with spokeperson(s) from SINP.

Hall B – Run Groups

HALL B

E12-06-109	Longitudinal Spin Structure of the Nucleon	Kuhn	A	80	185	Polarized target RICH (1 sector) Forward tagger	11	C S. Kuhn	NH_3 ND_3
E12-06-109A	DVCS on the neutron with polarized deuterium target	Niccolai		(60)					
E12-06- 119(b)	DVCS on longitudinally polarized proton target	Sabatie	A	120					
E12-07-107	Spin-Orbit Correl. with Longitudinally polarized target	Avakian	A-	103					
E12-09-007(b)	Study of partonic distributions using SIDIS K production	Hafidi	A-	80					
E12-09-009	Spin-Orbit correlations in K production w/ pol. targets	Avakian	B+	103					
E12-06-106	Color transparency in exclusive vector meson production	Hafidi	B+	60	60		11	D	
E12-06-117	Quark propagation and hadron formation	Brooks	A-	60	60		11	E	Nuclear
E12-06-113	Free Neutron structure at large x	Bueltman	A	42	42	Radial TPC	11	F	Gas D_2
E12-14-001	EMC effect in spin structure functions	Brooks	B+	55	55	Pol. LiH target	11	G	LiH
TOTAL CLAS12 run time (approved experiments)				**1466 (2118)**	**631**				

Proposal	Physics	Contact	Rating	Days	Group	Equipment	Energy	Group	Target
C12-11-111	SIDIS on transverse polarized target	Contalbrigo	A	110	110	Transverse target	11	H	HD
C12-12-009	Transversity w/ di-hadron on transvere target	Avakian	A	110					
C12-12-010	DVCS with transverse polarized target in CLAS12	Elouadrhriri	A	110					
All CLAS12 transverse target proposals				330	110				
E12-11-006	Heavy Photon Search at Jefferson Lab (HPS)	Jaros	A	180	180	Setup in alcove	2.2, 6.6	I	Nuclear
E12-11-106	High Precision Measurement of the Proton Charge Radius	Gasparian	A	15	15	Primex	1.1, 2.2	J	H2 gas
Beam time request from CLAS12 C1 experiments + non-CLAS12 experiments				**525**	**305**				
Beam time from approved CLAS12 experiments (from previous table)				**1466 (2118)**	**631**				
Beam time for Hall B experiments table 1 + table 2 (incl. 110 days of C1 approved exp.)				**1991 (2643)**	**936**				

Hall B – Run Groups

HALL B

Proposal	Physics	Contact	Rating	Days	Group	Equipment	Energy	Group	Target
E12-16-010	A search for Hybrid Baryons in Hall B with CLAS12	D'Angelo	A-	(100) ★	100	Forward Tagger	6.6, 8.8	K Confinement & Strong QCD	IH2
E12-16-010A	Nucleon Resonances in exc. KY electroproduction	Carman	A-	(100) ★					
E12-16-010B	DVCS with CLAS12 at 6.6 and 8.8 GeV	Elouadrhiri	A-	(100)					
Total Beam time of Run Group K				**100 (300)**	**100**				
Beam time of approved & C1 approved CLAS12 experiments from table 1 + table 2				**1991 (2643)**	**936**				
Beam time for Hall B experiments table 1 + table 2 + table 3				**2091 (2943)**	**1036**				

Proposal Count	Experiment Days	Run Groups	RG days	Compression
37	**2943**	**11**	**1036**	**0.35**

In the BOAW we expect experiment schedule:

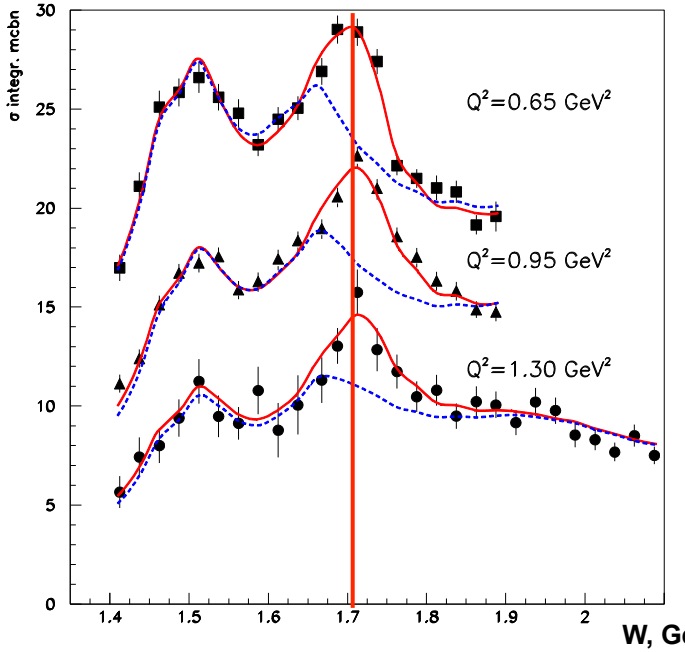
- 35 weeks per year ≈ 35/2 = 17.5 PAC weeks = 122.5 PAC days
- With 0.8 Hall multiplicity => 122.5 x 0.8 = 98 PAC days

- To run 2943 PAC days of individual experiments = **30 years**
- Run 2943 PAC days as run groups = 1036/98 = **10.5 years**

(★) **Experiments with spokeperson(s) from SINP.**

Back up

Evidence for the New State N'(1720)3/2$^+$ from Combined Analyses of $\pi^+\pi^-$p Photo- and Electroproduction off Protons



The structure at W~1.7 GeV represents the major feature for W-dependencies of fully integrated cross sections at 0.5 GeV^2 < Q^2 < 5.0 GeV^2 (see also slide # 25).

N(1740)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(1740)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.

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

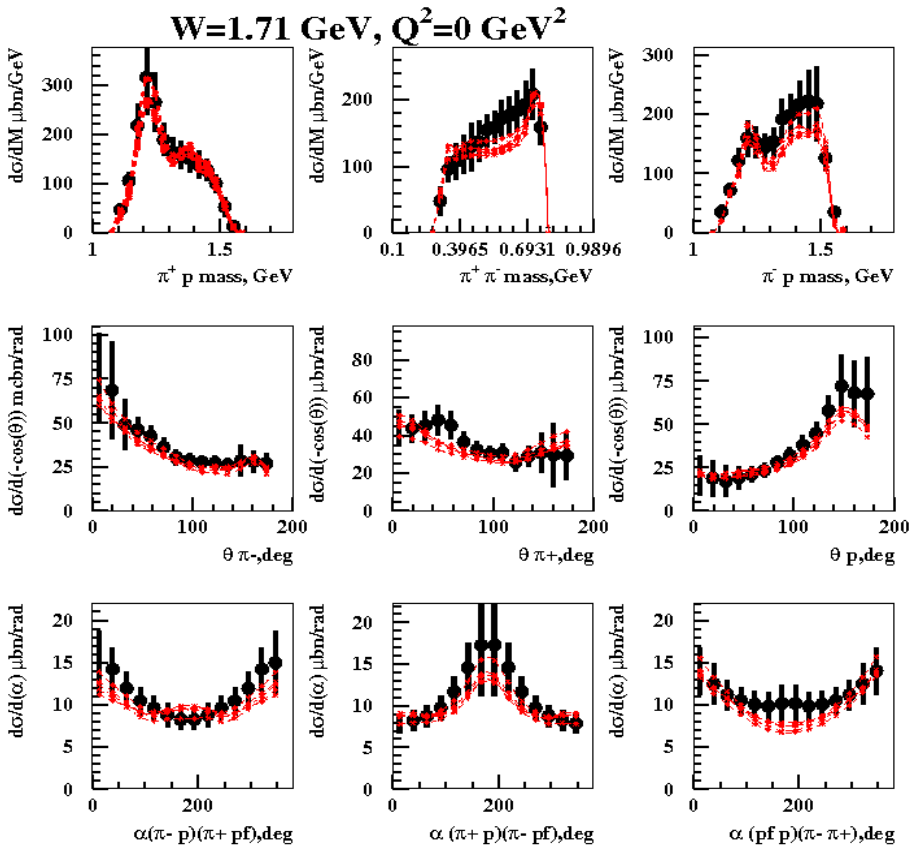
Resonance	BF($\pi\Delta$), %	BF(ρp), %
N'(1720)3/2$^+$		
electroproduction	47-64	3-10
photoproduction	46-62	4-13
N(1740)3/2$^+$		
electroproduction	39-55	23-49
photoproduction	38-53	31-46
Δ(1700)3/2$^-$		
electroproduction	77-95	3-5
photoproduction	78-93	3-6

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.

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

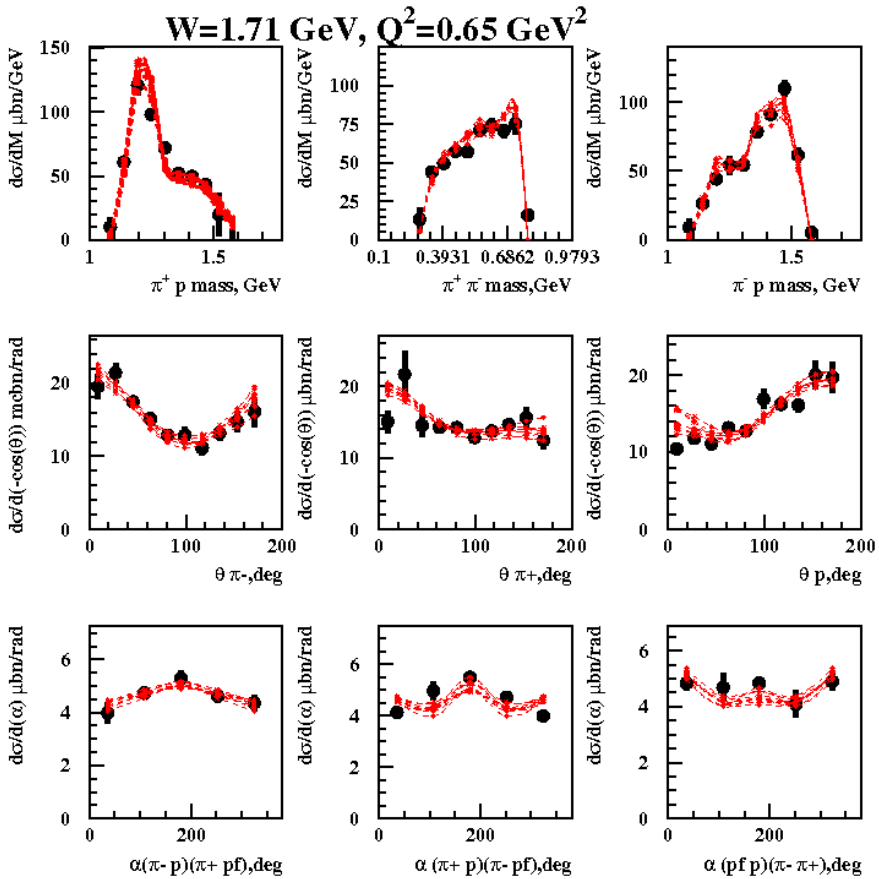
Photoproduction

$1.17<\chi^2/d.p.<1.31$ (1.66 GeV<W<1.76 GeV)



Electroproduction

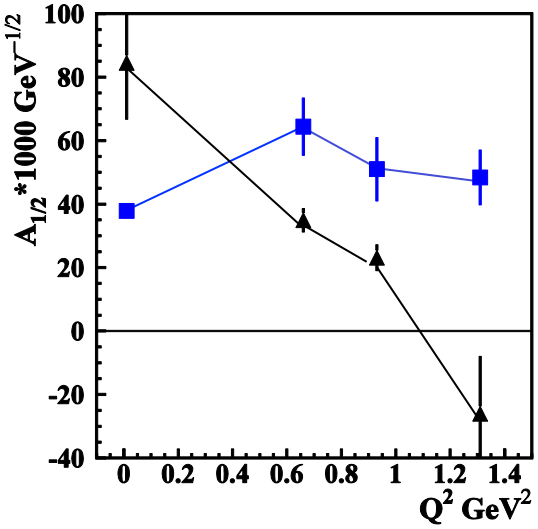
$2.56<\chi^2/d.p.<2.80$ (1.66 GeV<W<1.76 GeV)

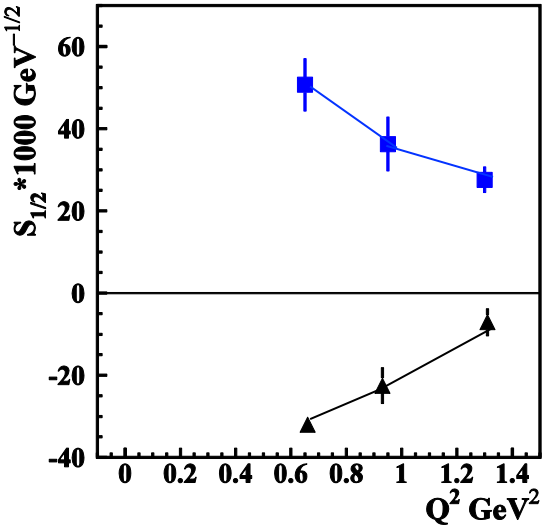


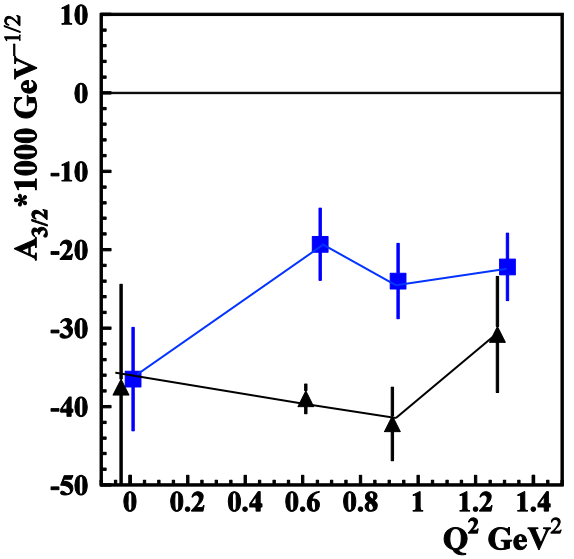
- Fit of θ_{π^-}, θ_{π^+}, θ_p angular distributions requires essential contribution(s) from the resonance(s) of $J^\pi=3/2^+$.
- Fits with conventional states only and by implementing in addition N'(1720)3/2+ candidate provide equally good data description.
- Accounting for the known resonances only results in contradictory values for the N(1740)$3/2^+$ BF to ρp final state inferred from the photo- and the electroproduction data (see slide #23)

The Parameters of N'(1720)3/2$^+$ and N(1740)3/2$^+$ from the CLAS Data Fit

The photo-/electrocouplings of N'(1720)3/2$^+$ and conventional N(1740)3/2$^+$ states:







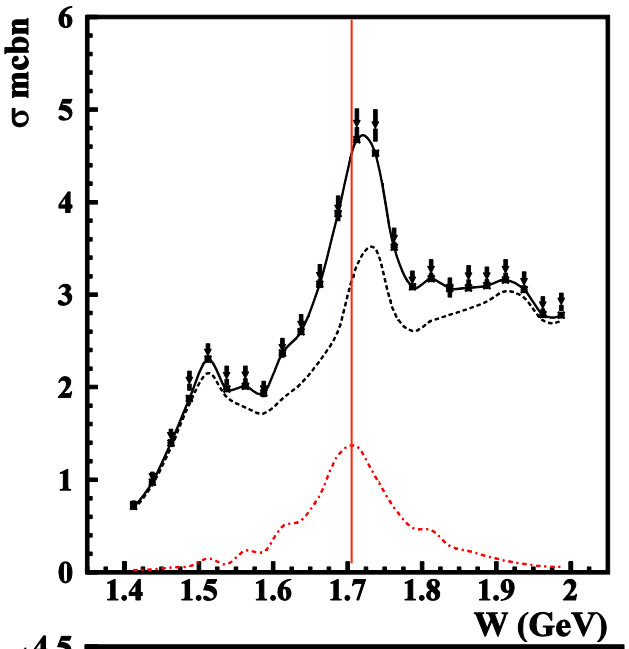
N'(1720)3/2$^+$

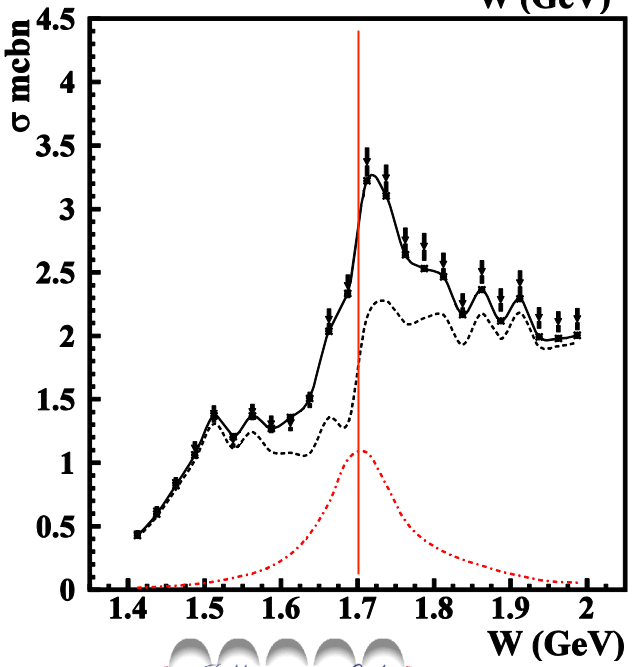
N(1740)3/2$^+$

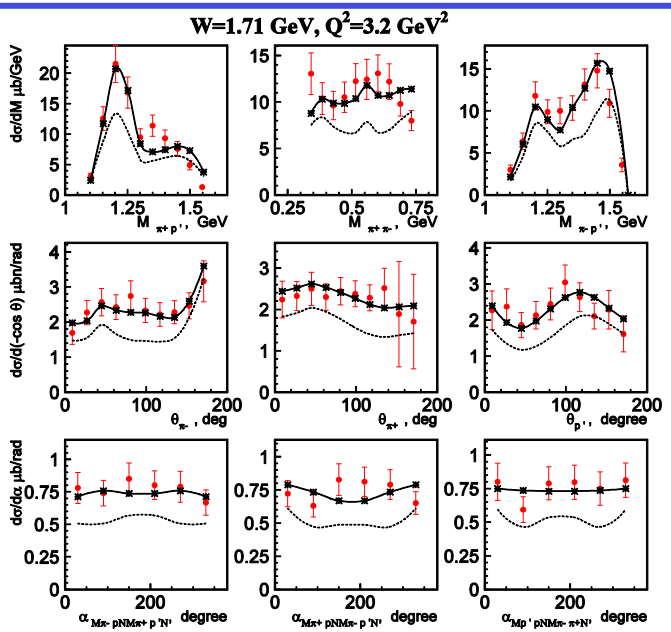
Resonance	Mass, GeV	Total width, MeV
N'(1720)3/2$^+$	1.715-1.735	120±6
N(1740)3/2$^+$	1.743-1.753	112±8

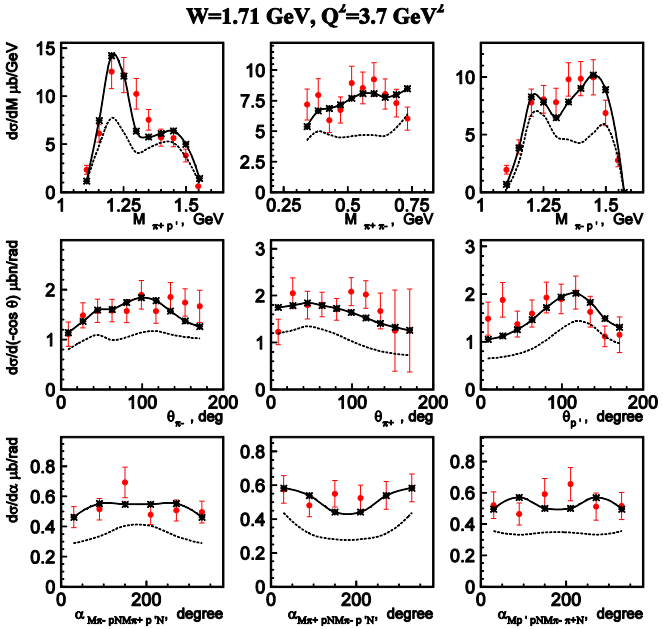
- N'(1720)3/2$^+$ is the only candidate state for which Q^2-evolution of transition electrocouplings have been obtained offering insight to the structure of the new baryon state.
- DSE evaluation of the N* spectrum for the states of J^π=3/2$^+$ with realistic ansatz for qq-interaction.
- DSE computation of N'(1720)3/2$^+$ electrocouplings in order to trace the new state emergence from QCD.

N'(1720)3/2⁺ New State at 2.0 GeV² < Q² < 5.0 GeV²









Data description in the JM17 model:

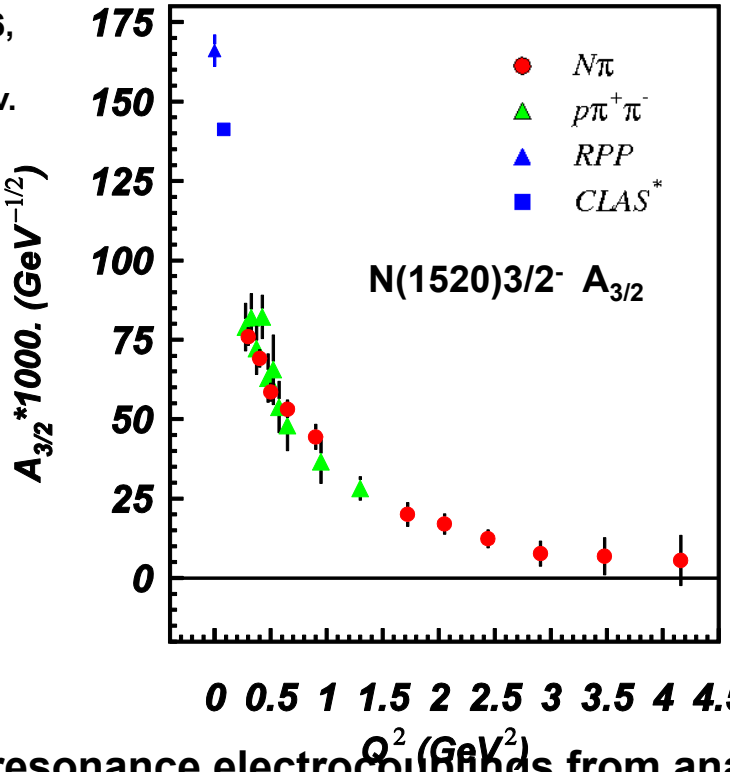
- full
- no N'(1720)3/2⁺
- difference with & without N'(1720)3/2⁺

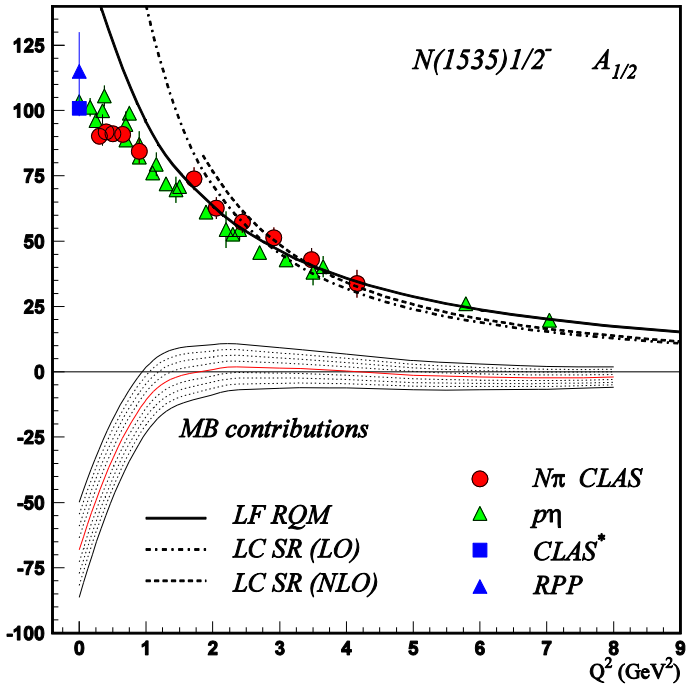
Clear manifestation of both N'(1720)3/2+ new and N(1740)3/2+ conventional states

.

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

H Denizli et al., Phys. Rev. C76, 015204 (2007).
I.G. Aznauryan et al., Phys. Rev. C80, 055203 (2009).
V.I. Mokeev et al., Phys. Rev . C86, 035203 (2012).
K. Park et al., Phys. Rev. C91, 052014 (2015).
V.I. Mokeev et al., Phys. Rev . C93, 054016 (2016).





Consistent values of resonance electrocouplings from analyses of $N\pi$/ $\pi^+\pi^- p$ and $N\pi/N\eta$ electroproduction off protons demonstrate the capabilities of the developed reaction models to obtain resonance electrocouplings in independent analyses of these exclusive channels.

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