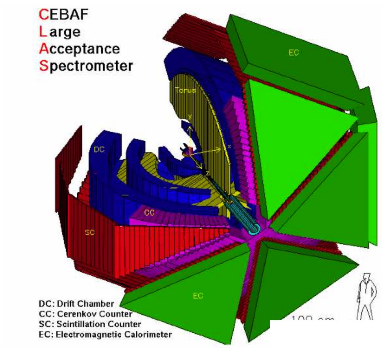
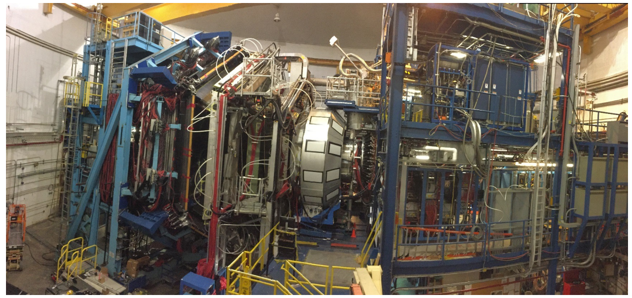
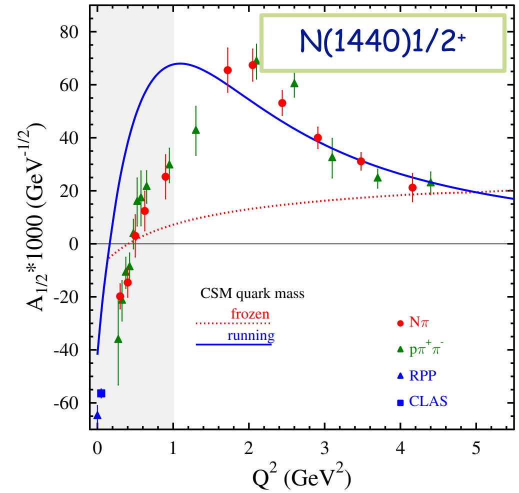
Nucleon Resonance Electrocouplings and the Emergence of Hadron Mass







- Theory advances in understanding of EHM from QCD
- Complementarity in gaining insight into EHM from the experimental results on pion, kaon, N/N* structure
- γ_vpN* electrocouplings from the data of JLab 6 GeV era
- Shedding light on EHM from the CLAS/Hall A/C γ_vpN* electrocouplings
- Extending insight into EHM from N* electroexcitation studies with CLAS12 and beyond

V.I. Mokeev, Jefferson Lab
(CLAS Collaboration)

Office of Science

Baryons 22 International Conference on the Structure of Baryons

N* Structure in Experiments of 6 GeV Era at JLab

The experimental program on the studies of N* structure in exclusive meson photo-/electroproduction with CLAS/CLAS12 as well as with the spectrometers in Halls A/C seeks to determine:

- $\gamma_v pN^*$ electrocouplings at photon virtualities Q^2 up to 10 GeV^2 for most excited proton states through analyzing the major meson electroproduction channels

- Explore hadron mass emergence (EHM) by mapping out the dynamical quark mass in the transition from almost massless pQCD quarks to fully dressed constituent quarks

An important part of the efforts on the exploration of strong QCD (sQCD) from the experimental data with electromagnetic probes:

1. S.J. Brodsky et al., Int. J. Mod. Phys. E29, 203006 (2020)
2. C.D. Roberts, Symmetry 12, 1468 (2020)
3. M. Barabanov et al., Prog. Part. Nucl. Phys. 103835 (2021)

A unique source of information on many facets of sQCD in generating excited nucleon states with different structural features:

1. V.I. Mokeev and D.S Carman, Few Body Syst. 63, 59 (2022)
2. D.S. Carman, K. Joo, and V.I. Mokeev, Few Body Syst. 61, 29 (2020)
3. V.D. Burkert and C.D. Roberts, Rev. Mod. Phys. 91, 011003 (2019)

How do the Ground/Excited Nucleon Masses Emerge?

Composition of the Nucleon Mass:

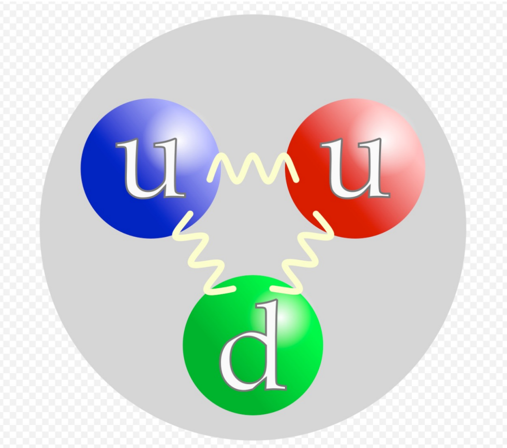
M_p, MeV (PDG20)

938.2720813
±0.0000058

Sum of bare quark masses, MeV

2.16+2.16+4.67
$=8.99^{+1.45}_{-0.65}$ or < 1.1%

proton



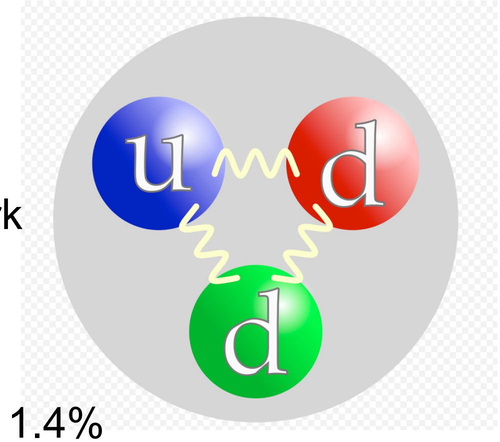
M_n, MeV (PDG20)

939.5654133
±0.0000058

Sum of bare quark masses, MeV

4.67+4.67+2.16
$= 11.50^{+1.45}_{-0.60}$ or < 1.4%

neutron

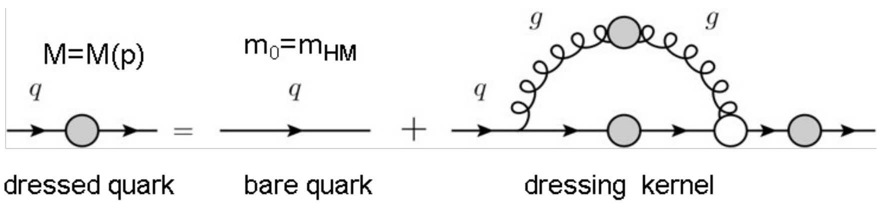


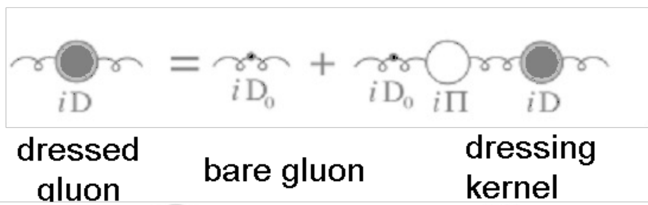
- **Higgs mechanism generates the masses of bare quarks.**
- **Dominant part of nucleon mass is generated in processes other than the Higgs mechanism.**

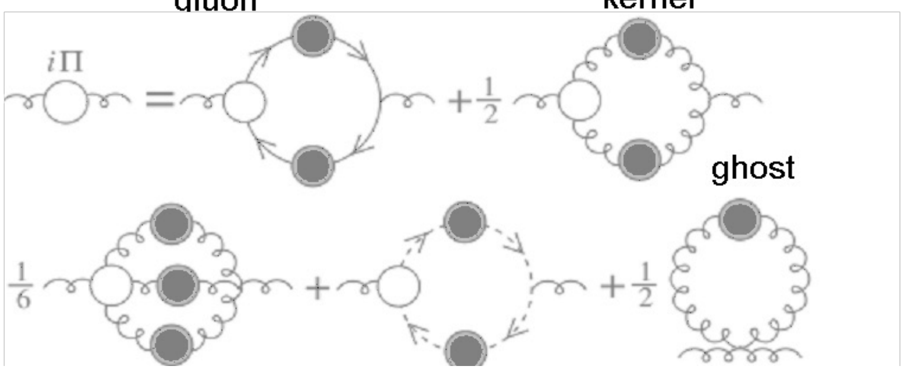
Studies of nucleon resonance electroexcitation within a broad range of Q^2 shed light on the emergence of the dominant part of hadron mass in the transition from the perturbative to quark-gluon confinement regimes of the strong interaction.

Basics for Insight into EHM: Continuum and Lattice QCD Synergy

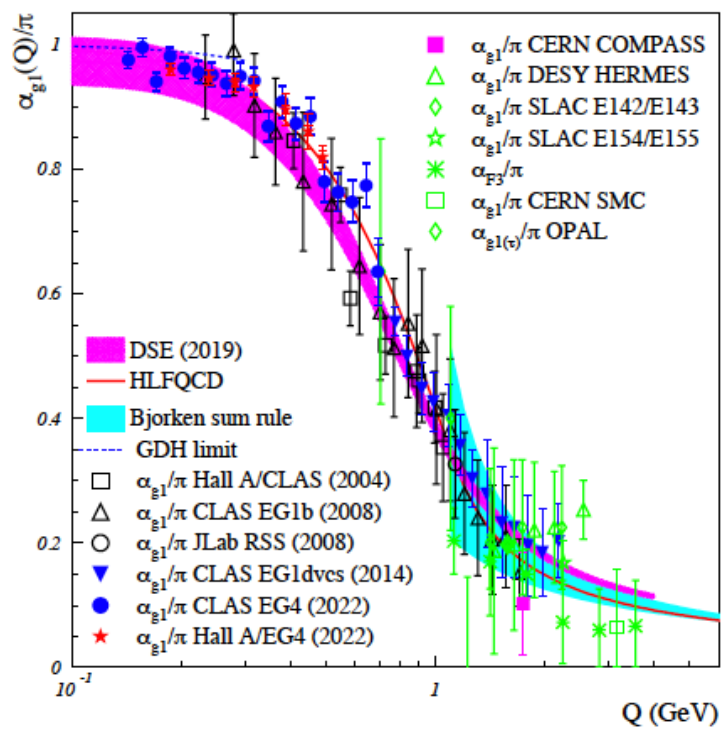
Emergence of Dressed Quarks and Gluons
D. Binosi et al., Phys. Rev. D 95, 031501 (2017)







QCD Running Coupling α(k)
Zh-F. Cui et al., Chin. Phys. C44, 083102 (2020)
A. Deur et al., Particles 5, 171 (2022)

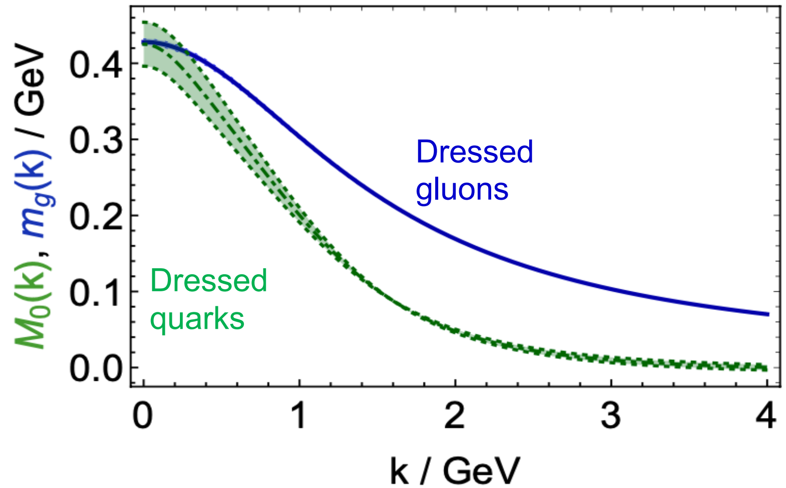


In the regime of the QCD running coupling comparable with unity, dressed quarks and gluons with distance (momentum) dependent masses emerge from QCD, as follows from the equations of the motion for the QCD fields depicted above

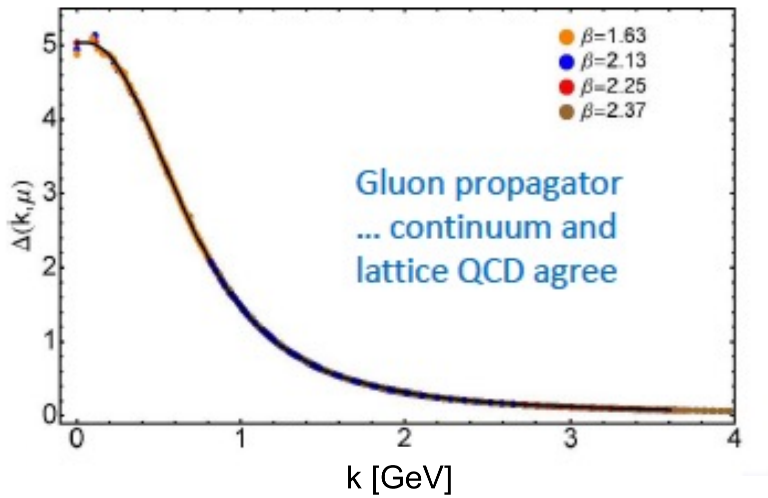
Basics for Insight into EHM: Continuum and Lattice QCD Synergy

- Dressed quark/gluon masses converge at the complete QCD mass scale of 0.43(1) GeV
- Express the fundamental feature: emergence of the quark and gluon masses even in the case of massless quarks in chiral limit and massless QCD gluons
- Continuum QCD results are confirmed by LQCD

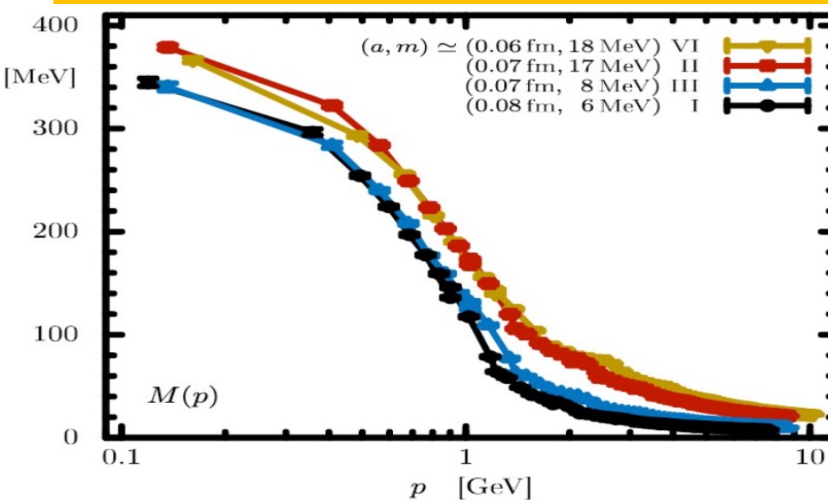
Dressed Quark/Gluon Masses (continuum QCD)
C.D. Roberts, Symmetry 12, 1468 (2020), AAPS Bull 31, 6 (2021)



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



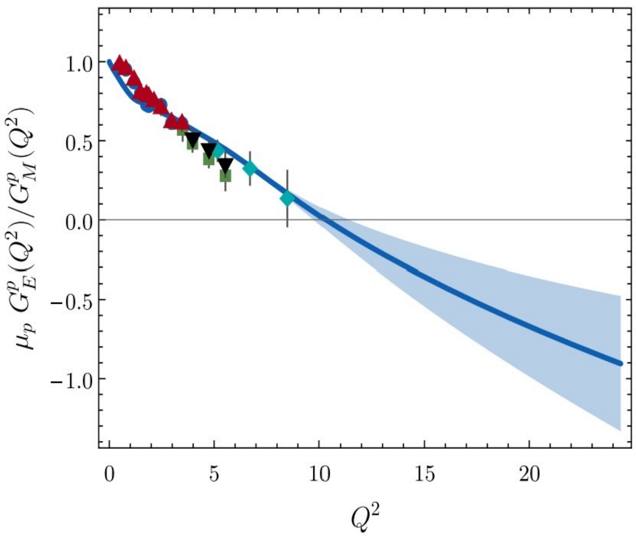
Dressed Quark Mass (lattice QCD)
O. Olivera et al., Phys. Rev. D 99, 094506 (2019)



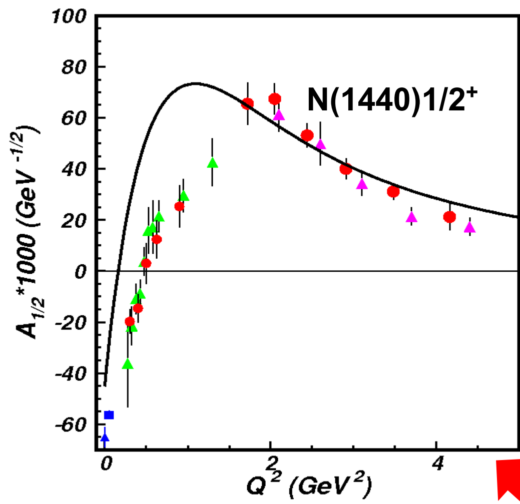
- Insight into dressed quark mass function from data on hadron structure represents a challenge for experimental hadron physics

EHM from Global Hadron Structure Analysis

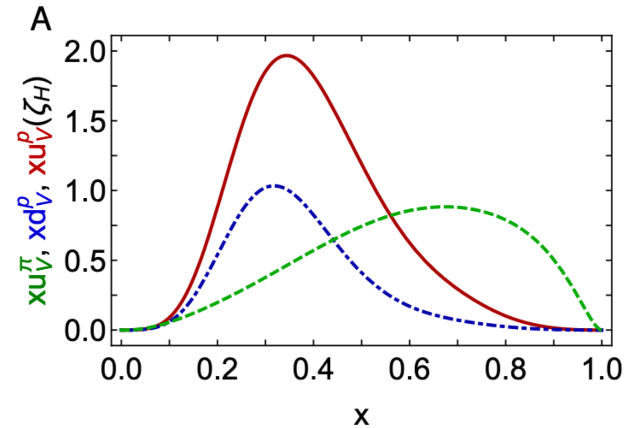
Nucleon Elastic FF



$\gamma_v pN^*$ Electrocouplings

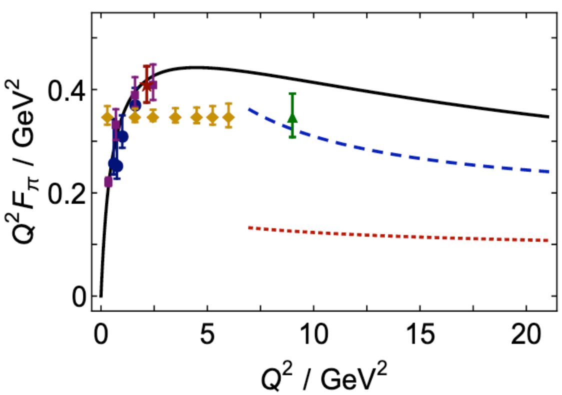


Proton and pion PDF for valence quarks

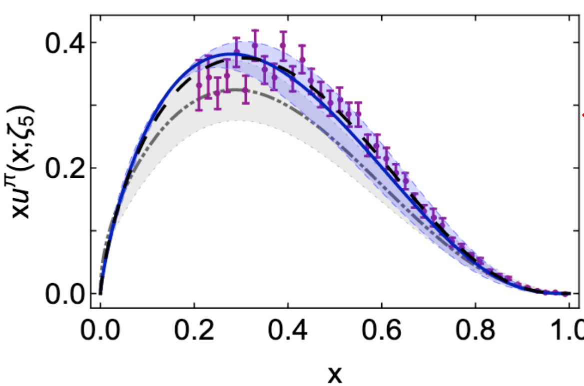


New data from studies of D-Y at AMBER and Sullivan processes at JLab

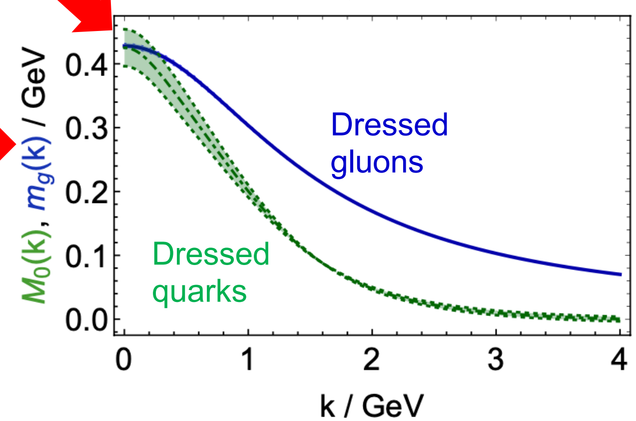
Pion Elastic FF



Pion PDF



Dressed Quark/Gluon Running Masses



- EHM is not expressed simply in the dressed-quark mass function. Instead, the dressed-quark mass function is one of the three pillars of EHM = gluon mass + QCD effective charge + quark mass. These pillars support an enormous array of predictions that go far beyond the quark model and far beyond what lattice QCD will be able to deliver in the foreseeable future.

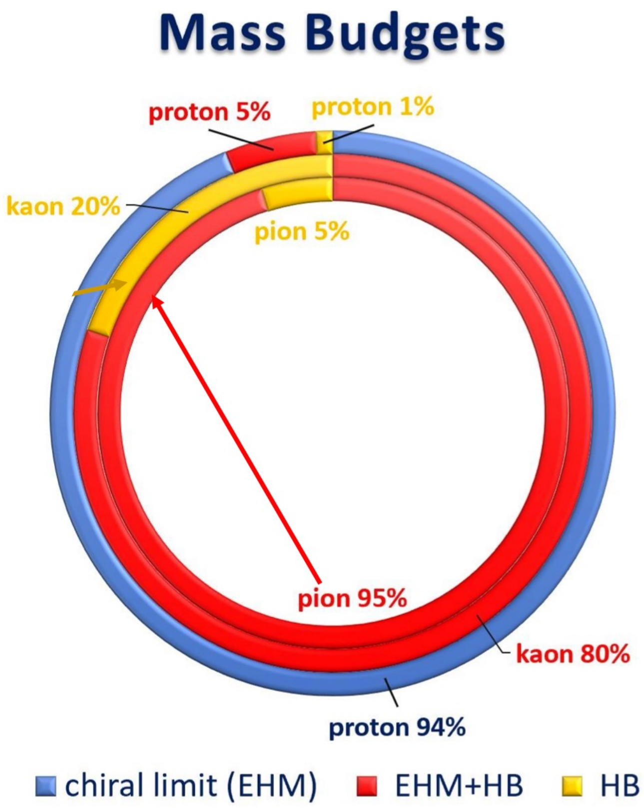
Insight into EHM from the Data on Pion/Kaon Structure

- The model, frame, and renormalization scheme/scale independent Goldberger-Treiman relations connect the momentum dependence of the dressed quark mass to the pion/kaon Bethe-Salpeter amplitudes, making the studies of pion and kaon structure a promising way to map out the momentum dependence of the dressed quark mass.

$$f_\pi E_\pi(p^2) = B(p^2)$$

- Pions and kaons are simultaneously $q\bar{q}$ bound states and Goldstone bosons in chiral symmetry breaking. Their masses should be reduced to zero in the chiral limit and, in the real world, down to small values in comparison with the hadron mass scale owing to DCSB.

Insight into EHM from the Data on N/N* Structure

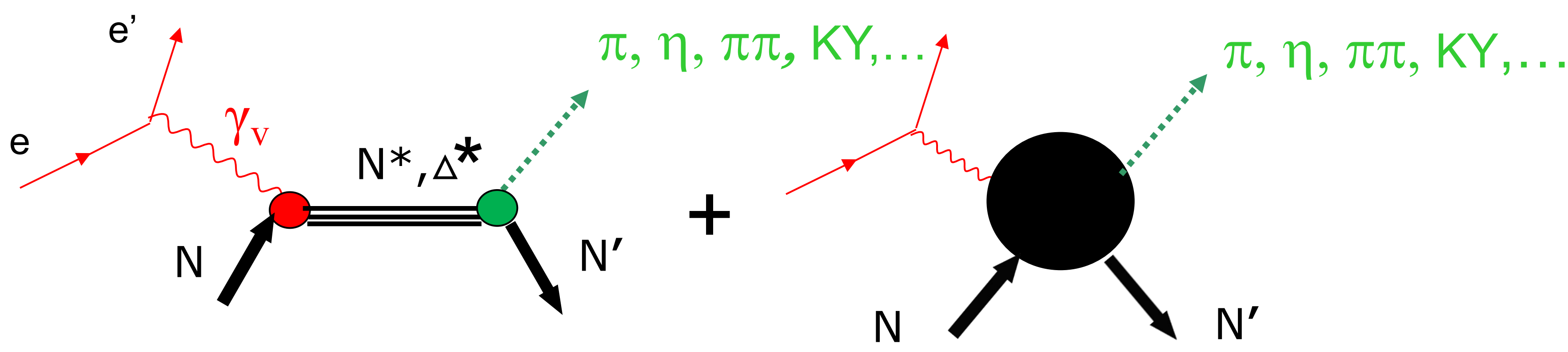


- Studies of π/K structure elucidate the interference between emergent and Higgs mechanisms in EHM
- Studies of ground/excited state nucleon structure allow us to explore the dressed quark mass function in a different environment where the sum of dressed quark masses is the dominant contribution to the physical masses of these states, offering insight into emergent mechanisms

- The successful description of the π/K elastic FF and PDF, nucleon elastic/axial FFs, and the $\gamma_v pN^*$ electrocouplings of prominent nucleon resonances of different structure achieved with the *same* dressed quark mass function is of particular importance for the validation of insight into EHM.

N* Photo-/Electroexcitation Amplitudes ($\gamma_{r,v}pN^*$ Photo-/Electrocouplings) and their Extraction from Exclusive Photo-/Electroproduction Data

Resonant amplitudes **Non-resonant amplitudes**



- **Real $A_{1/2}(Q^2)$, $A_{3/2}(Q^2)$, $S_{1/2}(Q^2)$**

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

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

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

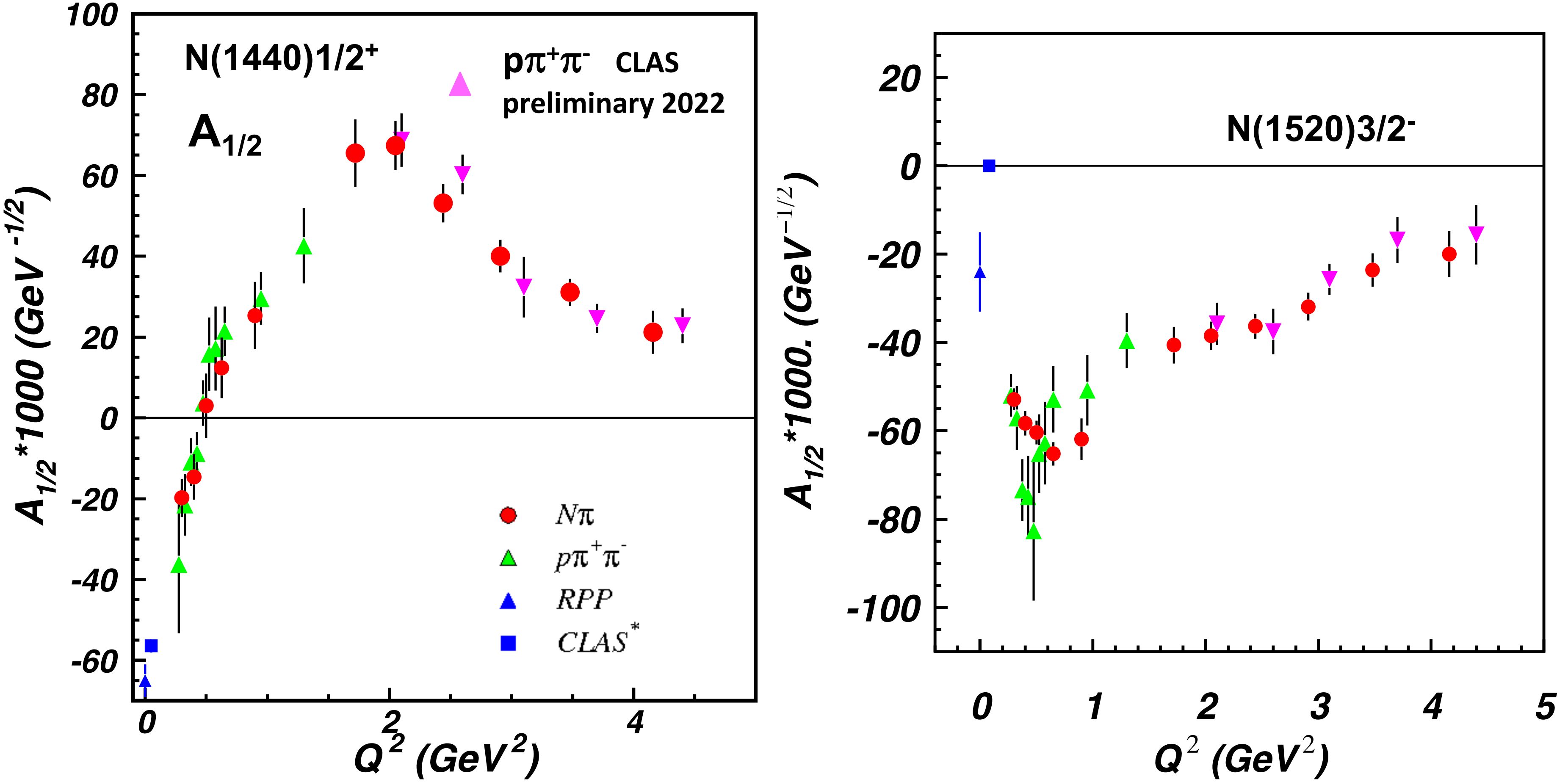
- **Consistent results on $\gamma_{r,v}pN^*$ photo-/electrocouplings from different meson photo-/electro-production channels allow us to validate reliable extraction of these quantities.**

Nucleon Resonance Electrocouplings from Data On Exclusive Meson Electroproduction of 6 GeV Era at JLab

Exclusive meson electroproduction channels	Excited proton states	Q^2-ranges for extracted $\gamma_v pN^*$ electrocouplings, GeV^2
$\pi^0 p$, $\pi^+ n$	$\Delta(1232)3/2^+$ $N(1440)1/2^+$, $N(1520)3/2^-$, $N(1535)1/2^-$	0.16-6.0 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
$\pi^+\pi^- p$	$N(1440)1/2^+$, $N(1520)3/2^-$ $\Delta(1620)1/2^-$, $N(1650)1/2^-$, $N(1680)5/2^+$, $\Delta(1700)3/2^-$, $N(1720)3/2^+$, $N'(1720)3/2^+$	0.25-1.50 2.0-5.0 (preliminary) 0.5-1.5

- **The $\gamma_v pN^*$ electrocouplings have become available from analysis of CLAS data for most excited states of the nucleon in the mass range <1.8 GeV and in a broad range of Q^2<5 GeV^2.**
- **The experiments in Halls A/C extended the results on the $\gamma_v pN^*$ electrocouplings of $\Delta(1232)3/2^+$ and $N(1535)1/2^-$ for $Q^2 < 7.5$ GeV^2**
- **The recent results can be found in:** A.N. Hiller Blin et al, PRC100, 035201 (2019).

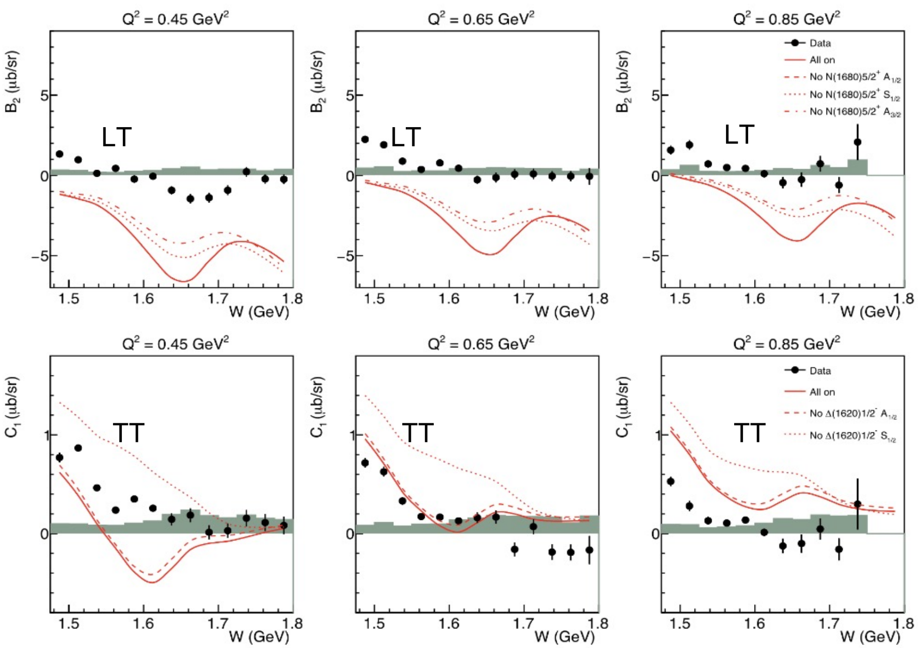
Electrocouplings of N(1440)1/2⁺ and N(1520)3/2⁻ Resonances from πN and $\pi^+\pi^-p$ Electroproduction off Proton Data



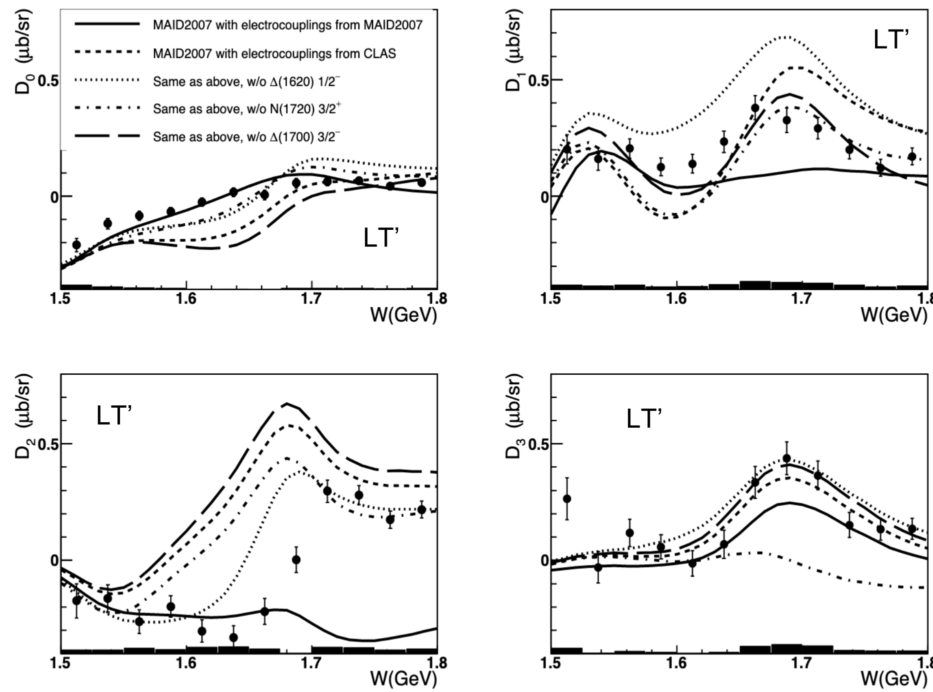
Consistent results on the N(1440)1/2⁺ and N(1520)3/2⁻ electrocouplings from independent studies of the two major πN and $\pi^+\pi^-p$ electroproduction channels with different non-resonant contributions allow us to evaluate the systematic uncertainties of these quantities in a nearly model-independent way.

Extension of the Results on $\pi^0 p$ Electroproduction with CLAS for Extraction of $\gamma_v pN^*$ Electrocouplings

N.Markov et al, (CLAS Coll.) Phys. Rev. C101, 015208 (2020)



E. L. Isupov et al, (CLAS Coll.) Phys. Rev. C105, L022201 (2021)



Legendre moments from $\pi^0 p$ electroproduction structure functions measured with CLAS at W<1.8 GeV and at $0.4<Q^2<1.0$ GeV^2 demonstrate pronounced sensitivity to variation of the $\gamma_v pN^*$ electrocouplings for the resonances in mass range from 1.6 GeV to 1.8 GeV offering the good prospects to extend the results on electroexcitation amplitudes for the resonances in the third resonance region..

The Results on $\pi^+\pi^-p$ Electroproduction with CLAS for Extraction of $\gamma_v pN^*$ Electrocouplings

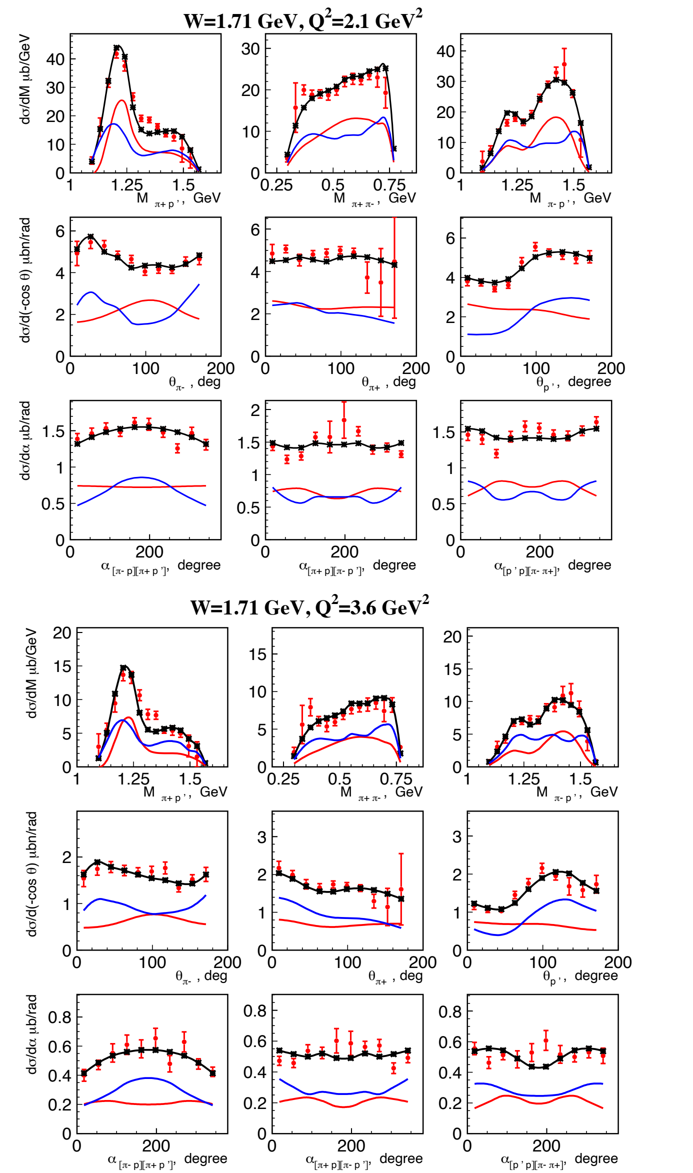
A.Trivedi Few Body Syst. 60, 5 (2019)
E.L Isupov et al. (CLAS Collaboration), Phys. Rev. C96, 025209 (2017)

V.I. Mokeev, EPJ Web Conf 241, 03003(2020)

Full

Resonances

Background

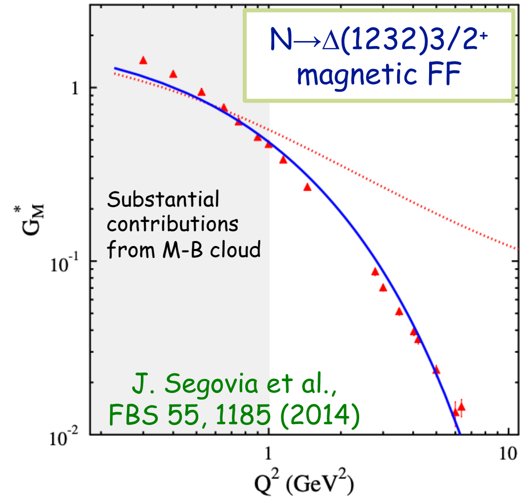


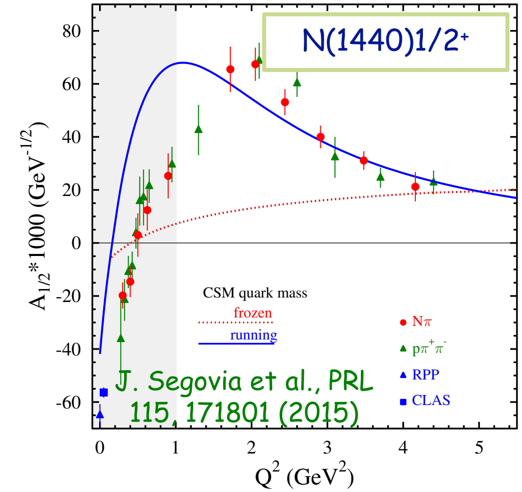
In near future, electrocouplings of nucleon resonances in the mass range from to 2 GeV and $Q^2 < 5$ GeV^2 will be determined, concluding the studies of N* structure from meson electroproduction data from 6 GeV era at JLab.

EHM: Concept from CSM vs. Available Experimental Results

CLAS/Hall A/C results vs. CSM expectations

- A successful description of the pion and nucleon elastic FFs, and the electrocouplings of the Δ(1232)3/2⁺ and N(1440)1/2⁺ resonances has been achieved *with the same dressed quark/gluon mass functions*





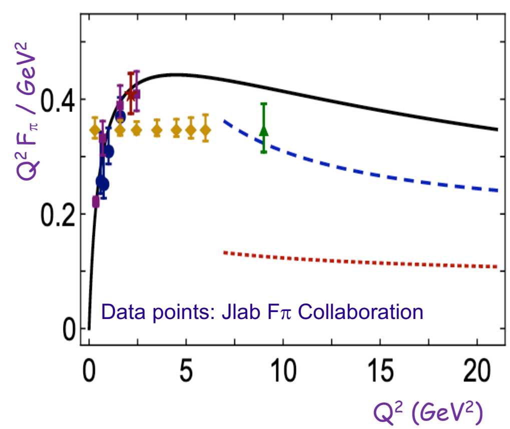
Pion Elastic FF

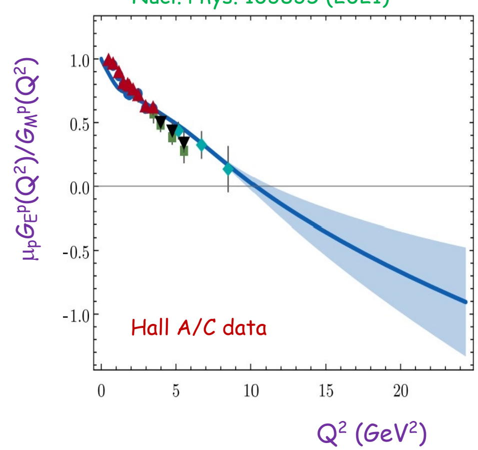
C.D. Roberts et al., Prog. Part. Nucl Phys. 120, 103883 (2021)

Nucleon Elastic FF

M. Barabanov et al., Prog. Part. Nucl. Phys. 103835 (2021)

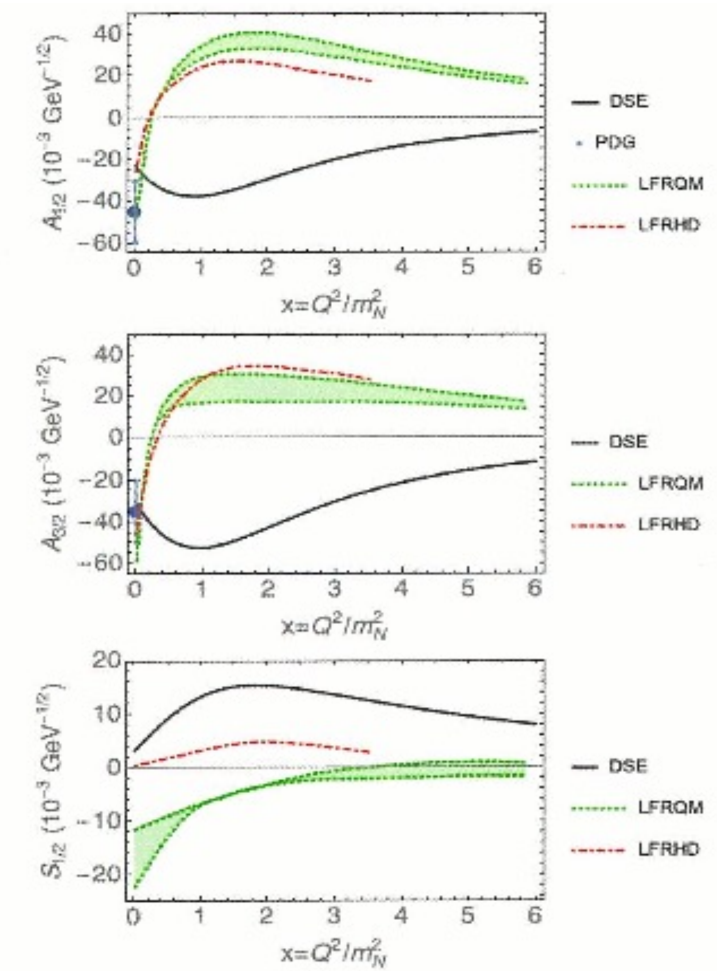
- *Dressed quarks with dynamically generated masses represent active degrees of freedom in the structure of the pion, nucleon, and the* Δ(1232)3/2⁺, N(1440)1/2⁺ resonances
- ***Strong evidence for insight into momentum dependence of dressed quark mass***





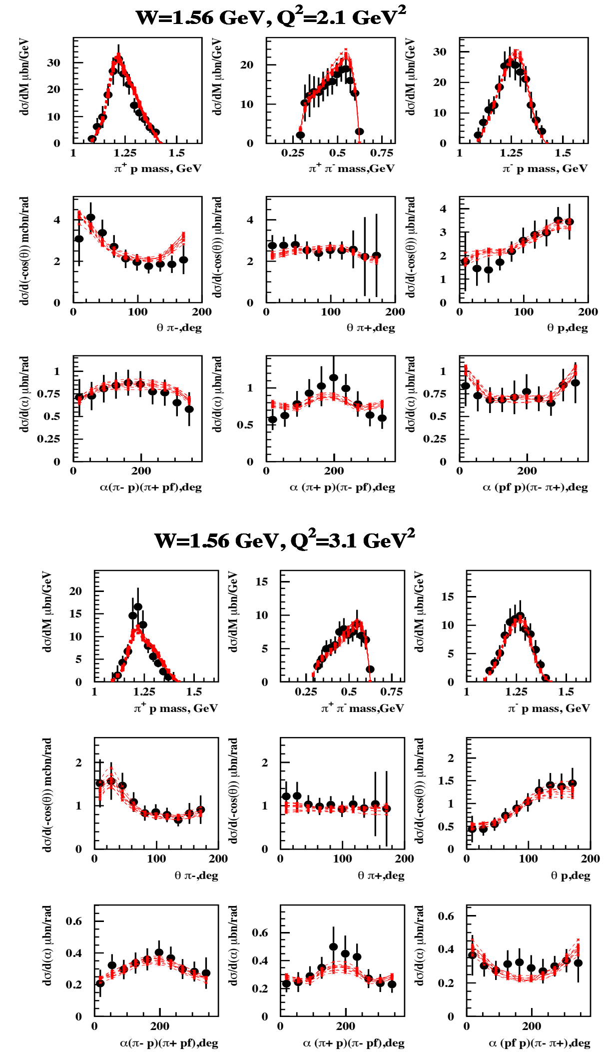
One of the most important achievements in hadron physics of the last decade in synergistic efforts between experimentalists, phenomenologists, and theorists.

$\Delta(1600)3/2^+$ Electrocouplings: CSM Prediction vs. Data Determination

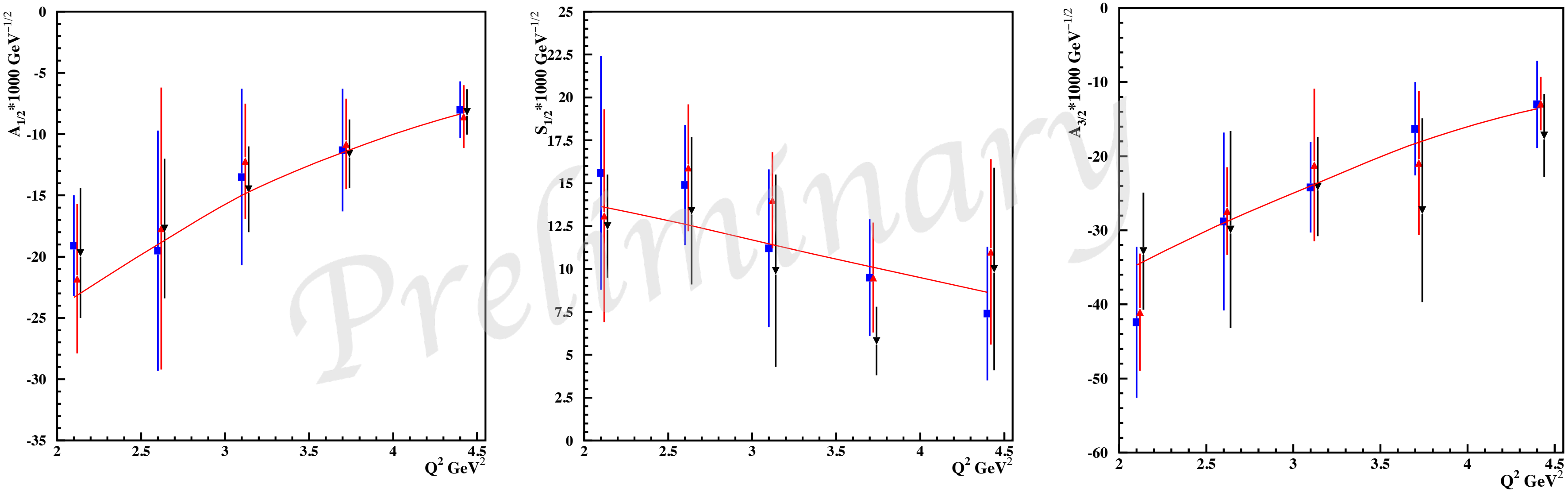


Parameter-free CSM predictions for $\Delta(1600)3/2^+$ electrocouplings
Ya Lu et al., Phys. Rev. D 100, 034001 (2019)

Extraction of $\Delta(1600)3/2^+$ electrocouplings from the CLAS $\pi^+\pi^-p$ electroproduction data at 2.0 GeV^2<Q^2<5.0 GeV^2 within the JM reaction model, January-March, 2022



$\Delta(1600)3/2^+$ Electrocouplings : CSM Prediction vs. Data Determination



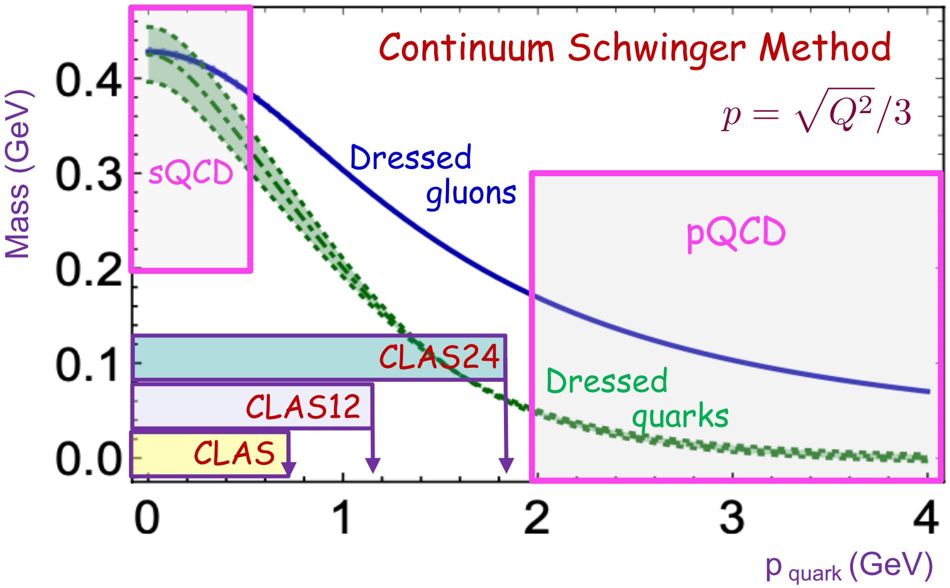
CSM predictions, Ya Lu et al., Phys. Rev. D 100, 034001 (2019)

Electrocouplings from independent analyses of $\pi^+\pi^-p$ differential cross sections within three W-intervals, 1.46<W<1.56 GeV, 1.51<W<1.61 GeV, and 1.56<W<1.66 GeV for 2.0<Q^2<5.0 GeV^2

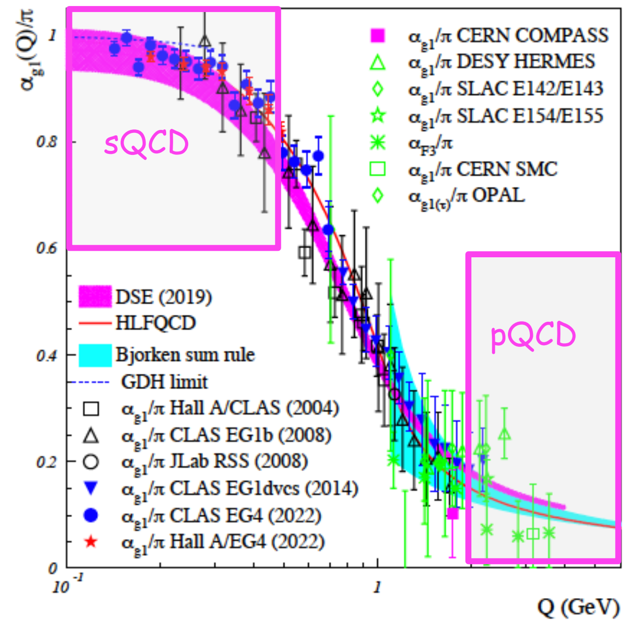
CLAS results on $\Delta(1600)3/2^+$ electrocouplings confirmed the CSM prediction, solidifying evidence for gaining insight into dressed quark mass function and, consequently, into EHM from the studies of $\gamma_v pN^*$ electrocouplings

Unique Opportunities to Understand Emergence of Hadron Mass and N* Structure from the Measurements with CLAS12 and After CEBAF 20⁺ GeV Energy Upgrade

Running Dressed Quark/Gluon Masses from CSM
C.D. Roberts, Symmetry 12, 1468 (2020), AAPS Bull 31, 6 (2021)



QCD Running Coupling
Zh-F. Cui et al., Chin. Phys. C44, 083102 (2020)
A. Deur et al., Particles 5, 171 (2022)

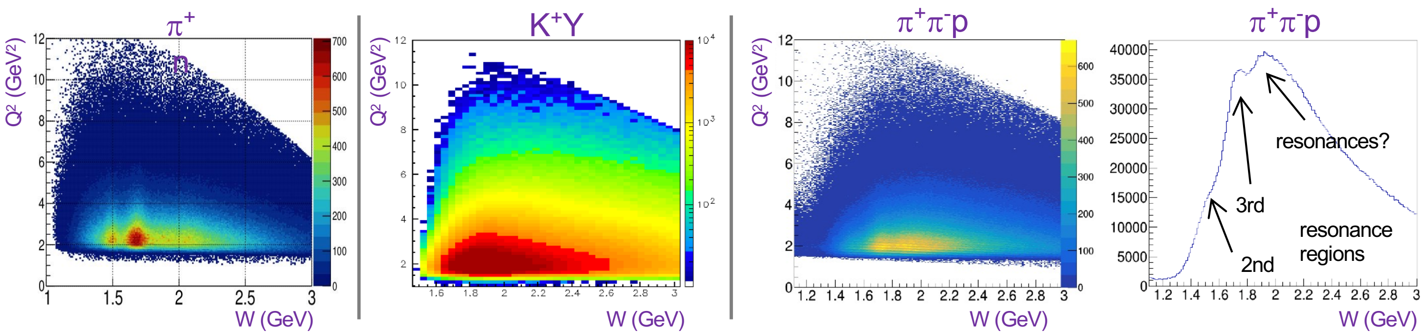


- In order to resolve the challenging open problem in the Standard Model on EHM, the dressed quark mass function $M_q(p)$ should be mapped out within the entire range of quark momentum to ~2 GeV, where the transition from strong to perturbative QCD takes place and where dressed quarks/gluons emerge as $\alpha_s/\pi \rightarrow 1$.
- CLAS12 is the only facility in the world capable of obtaining the electrocouplings of all prominent N* states in the still unexplored Q^2 range from 5 - 10 GeV^2, allowing for the mapping of the dressed quark mass function at quark momenta to ~1.1 GeV.

N* Electroexcitation to High Q^2 with CLAS12

Expected outcome: The first results on the $\gamma_v pN^*$ electrocouplings of most N* states from data in the range W < 2.5 GeV and $Q^2 > 5.0$ GeV^2 for exclusive reaction channels: πN, ππN, KY, K*Y, KY*

kinematic coverage for RG-A data @ 10.6 GeV



Expected events per Q^2/W bin for full RG-A dataset

π⁺n			K⁺Λ & K⁺Σ⁰					π⁺π⁻p		
Q^2 [GeV^2]	W [GeV] 1.5-1.55	W [GeV] 1.7-1.75	Q^2 [GeV^2]	W_Λ [GeV] 1.7-1.75	W_Σ [GeV] 1.7-1.75	W_Λ [GeV] 1.9-1.95	W_Σ [GeV] 1.9-1.95	Q^2 [GeV^2]	W [GeV] 1.7-1.75	W [GeV] 1.9-1.95
			1.4-2.2	63417	6012	66564	33170			
			2.2-3.0	72144	5364	77443	28720			
5.2-5.8	15272	4175	3.0-4.0	52358	3945	51991	18936	5.2-5.8	2813	2808
5.8-6.5	10737	2637	4.0-5.0	24833	3103	26690	5925	5.8-6.5	1822	1969
6.5-7.2	7367	1684	5.0-6.0	11203	1598	11160	2642	6.5-7.2	1159	1294
7.2-8.1	4567	1290	6.0-7.0	5566	648	6300	943	7.2-8.1	661	924
8.1-9.1	2742	540	7.0-8.0	2606	338	3276	633	8.1-9.1	364	414
9.1-10.5	1453	194	8.0-9.0	1440	244	936	86	9.1-10.5	118	179

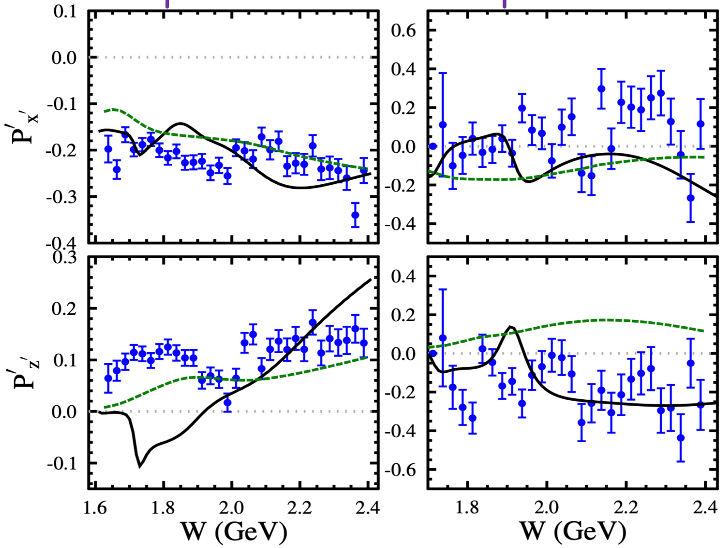
Collecting the remainder of the approved RG-A beam time will give a factor of two more statistics

This will extend the Q^2 range of the $\gamma_v pN^*$ electrocouplings to 8-10 GeV^2 for each of these channels – *the data collected so far will limit us to 6-8 GeV^2*

CLAS12 K^+Y Transferred Polarization

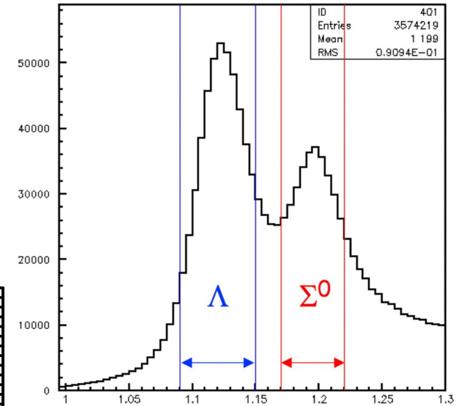
CLAS12 RG-K @ 6.535 GeV,
0.3< Q^2< 3.5 GeV^2

$ep \rightarrow e'K^+\Lambda$ $ep \rightarrow e'K^+\Sigma^0$

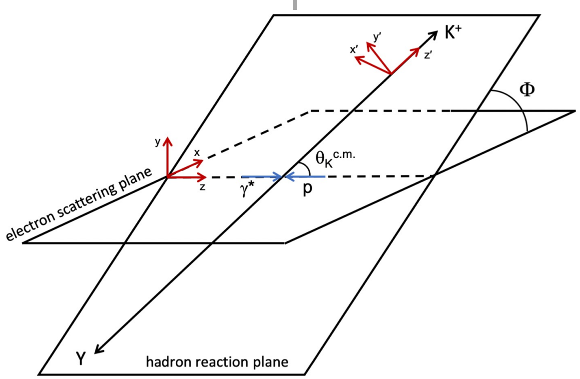


D.S. Carman et al., PRC 105, 065201 (2022)

KAON-MAID
RPR

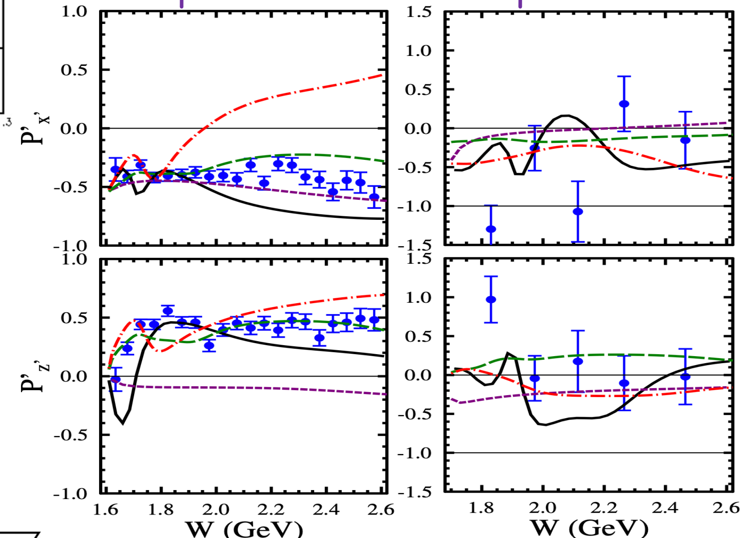


MM(e'K+) (GeV)



CLAS e1-6 @ 5.754 GeV
0.7< Q^2< 5.4 GeV^2

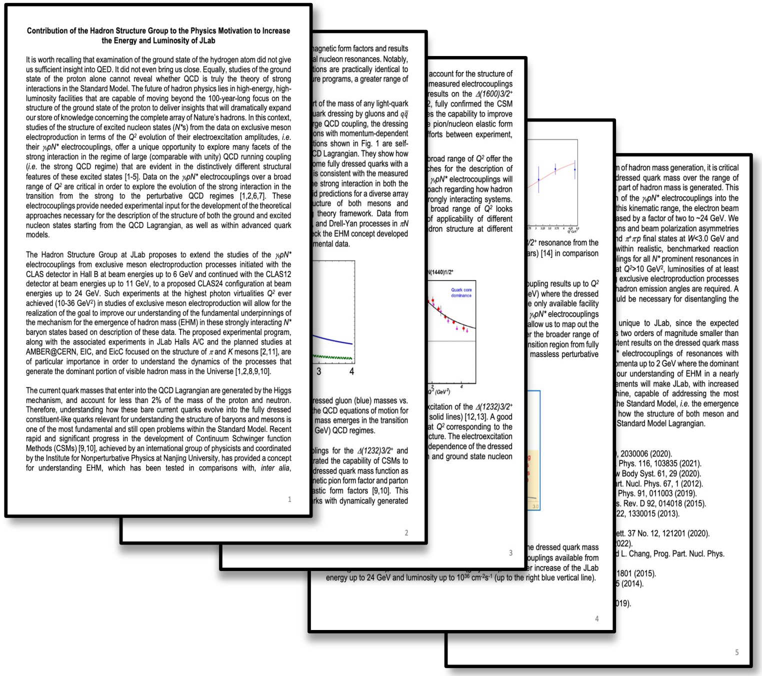
$ep \rightarrow e'K^+\Lambda$ $ep \rightarrow e'K^+\Sigma^0$



D.S. Carman et al., PRC 79, 065205 (2009)

Mart/Bennhold RPR-2
RPR-1 Regge

Hadron Structure Studies with CLAS20$^+$



Hadron Structure Group in Hall B developing physics case to support CLAS20$^+$ upgrade

https://userweb.jlab.org/~carman/clas24

List of Participating Institutions:

- Jefferson Lab (Hall B and Theory Division)
- University of Connecticut
- Genova University and INFN of Genova
- Lamar University
- Ohio University
- Skobeltsyn Nuclear Physics Institute and Physics Department at Lomonosov Moscow State University
- University of South Carolina
- INFN Sez di Roma Tor Vergata and Universita di Roma Tor Vergata
- Nanjing University Institute for Nonperturbative Physics and affiliated institutes
- Tubingen University
- Tomsk State University and Tomsk Polytechnic University
- James Madison University
- George Washington University

- Simulations of πN, KY, and $\pi^+\pi^- p$ electroproduction with CEBAF@20$^+$ GeV show:

  $\gamma_v pN^*$ electrocouplings can be determined up to $Q^2 \sim 30$ GeV^2 for $\mathcal{L} \sim 5 \times 10^{35}$ cm^{-2}s^{-1}

- Experimental confirmation of CSM predictions of $\gamma_v pN^*$ electrocouplings of most prominent N* states of different structure will provide sound evidence for the understanding how the dominant part of hadron mass and N* structure emerge from QCD

Conclusions and Outlook

- **Baryons are the most fundamental three-body systems in Nature. If we don't understand how QCD builds each of the baryons in the complete spectrum, then we don't understand Nature.**

- **High-quality meson electroproduction data of 6 GeV era at JLab have allowed for the determination of the electrocouplings of most nucleon resonances in the mass range up to 1.8 GeV for Q^2<7.5 GeV^2.**

- **A good description of the $\Delta(1232)3/2^+$, N(1440)1/2$^+$, and $\Delta(1600)3/2^+$ electroexcitation amplitudes at Q^2<5.0 GeV^2 *achieved within CSM with the same dressed quark mass function inferred from the QCD Lagrangian and* used in the successful description of the data on elastic nucleon and pion electromagnetic form factors, offers sound evidence for insight into the momentum dependence of the dressed quark mass.**

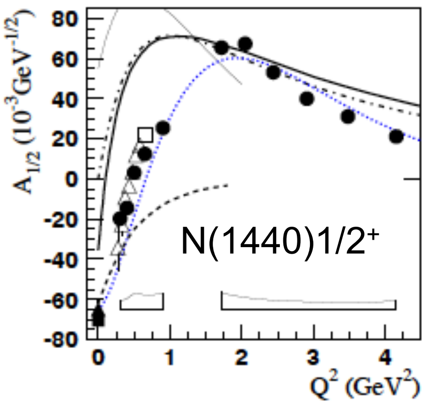
- **CLAS12 is the only facility in the world capable of obtaining the electrocouplings of all prominent N* states in the still unexplored Q^2 range from 5 - 10 GeV^2 from measurements of $N\pi$, $\pi^+\pi^-p$, and KY electroproduction, allowing for the mapping of the dressed quark mass function at quark momenta < 1.1 GeV where ~50% of hadron mass is generated.**

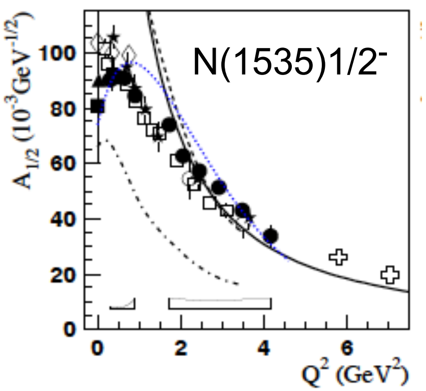
- **JLab20+ is the only envisaged facility that will enable science to produce a sufficient quantity of precise data on nucleon elastic and transition form factors that can move science toward an understanding of the most fundamental 3-body systems in Nature. *JLab20+ will provide the data that will enable science to draw the EHM map. That map will be a key part of the final solution of QCD.***

- **Extension of the results on the $\gamma_v pN^*$ electrocouplings into the Q^2 range from 10 - 30 GeV^2 after the increase of the CEBAF energy and pushing the CLAS12 detector capabilities to measure exclusive electroproduction to the highest possible luminosity, will offer the only foreseen opportunity to explore how the dominant part of hadron mass and N* structure emerge from QCD and will make CEBAF@20$^+$ GeV unique and the ultimate QCD-facility at the luminosity frontier.**

Back up

Facets of Strong QCD from Combined Studies of the Ground/Excited Nucleon State Structure



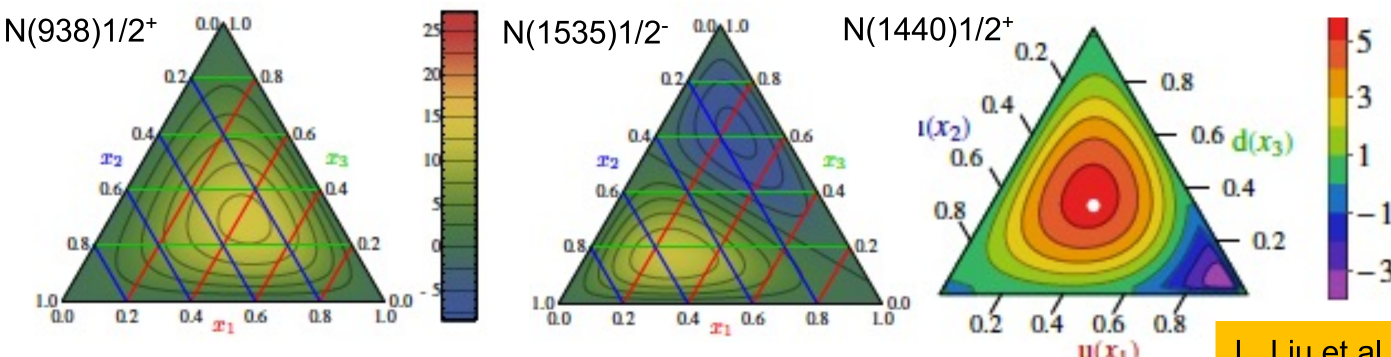


V.D.Burkert and I.G. Aznauryan, Prog. Part Nucl. Phys. 67, 1 (2012)

The results on electroexcitation of different resonances allow us to rigorously test the quark model ingredients for the description of the ground/excited hadron structure

V.M. Braun et al., Phys. Rev. D 89, 094511 (2014)
C. Mezrag et al., Phys. Rev. Lett. B 783, 263 (2018)

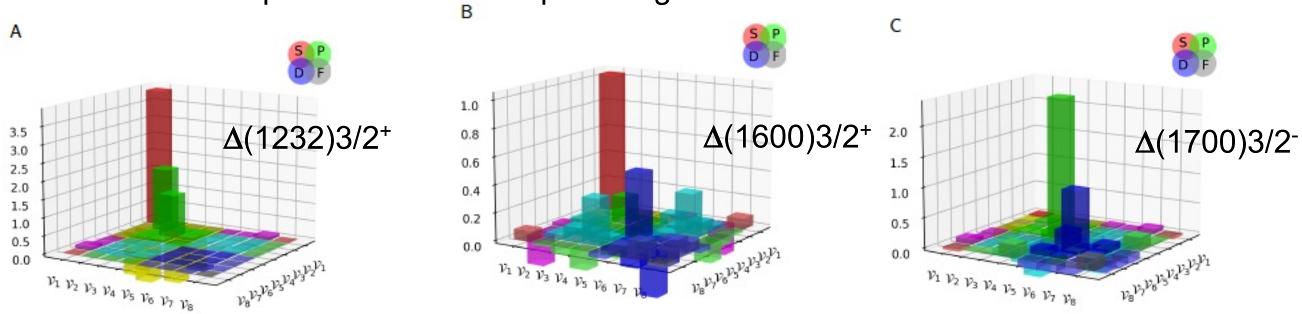
Parton distribution amplitudes (PDA) in:



Pronounced differences predicted for N/N* PDAs can be explored in N* electroexcitation, offering insight into the sQCD mechanisms that underlie these differences

L. Liu et al., e-print: 2203-12083 [hep-ph]

Rest frame quark-correlated-di-quark angular momentum content in:

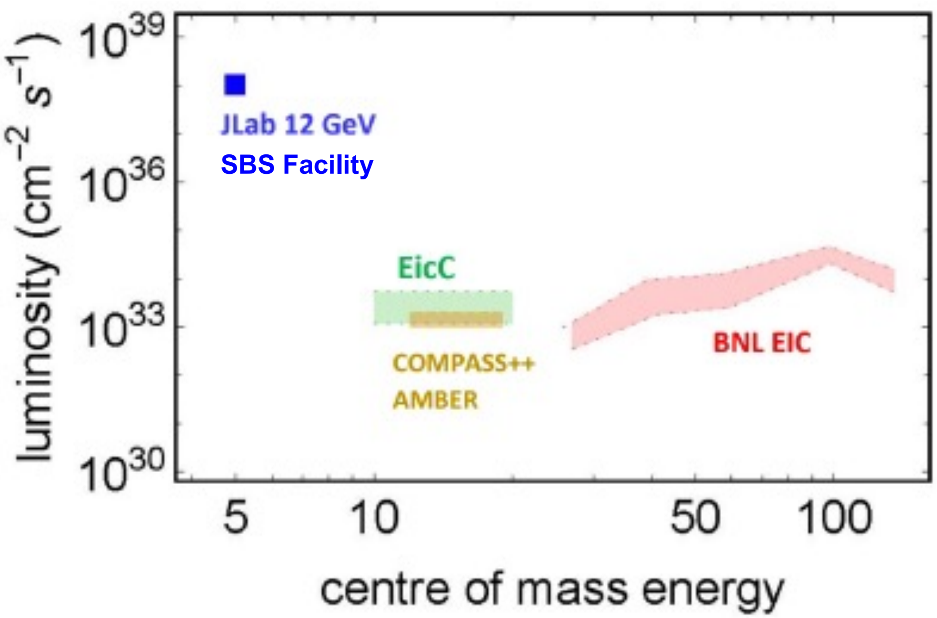


Studies of N* electroexcitation will contribute to understanding of the nature of spin of the ground and excited states of the nucleon

Exploration of N* electroexcitations is an important part of efforts aimed to considerably extend knowledge on sQCD

Studies of $\gamma_v pN^*$ Electrocouplings at $Q^2 > 10$ GeV^2

Energy and luminosity increase up to $5*10^{35}$ cm^{-2}s^{-1} are needed in order to obtain information on the $\gamma_v pN^*$ electrocouplings at Q^2>10 GeV^2, allowing us to map out the momentum dependence of the dressed quark mass within the entire range of distances where the dominant part of hadron mass is generated in the transition from sQCD to pQCD.



Both EicC and EIC would need much higher, unlikely feasible luminosity

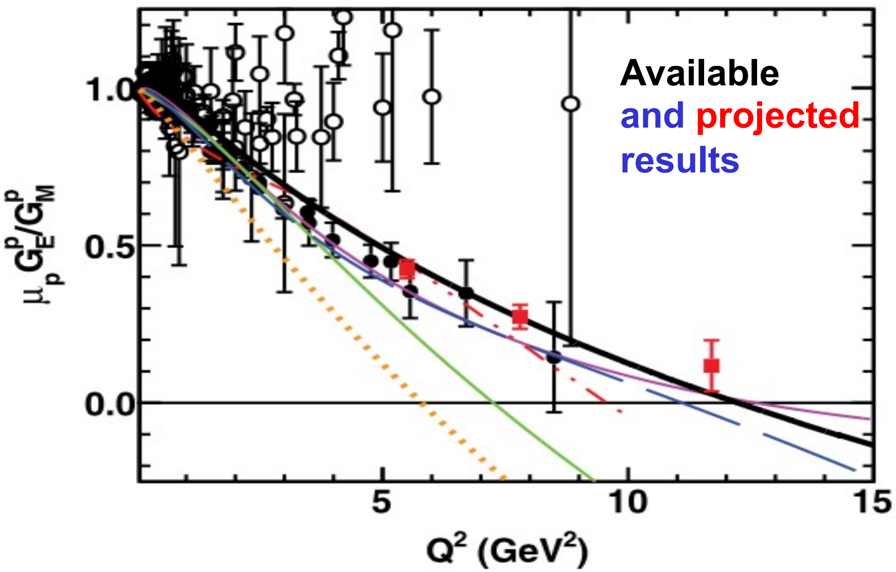
The exclusive electroproduction measurements foreseen at JLab after completion of the 12 GeV program:

- Beam energy at fixed target: 24 GeV
- Nearly 4π coverage
- High luminosity

Offer maximal achievable luminosity for extraction of $\gamma_v pN^*$ electrocouplings at Q^2>10 GeV^2

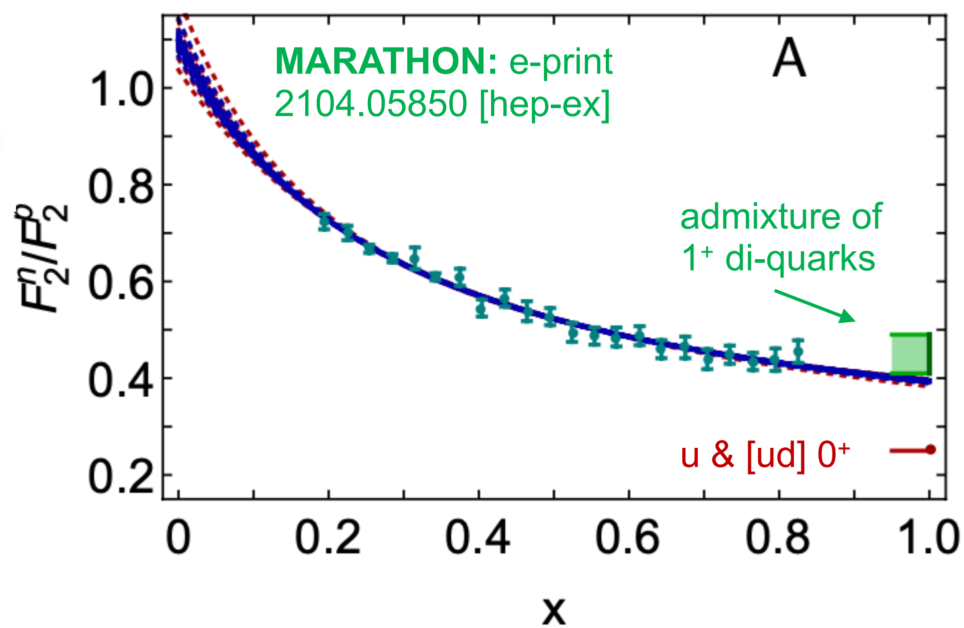
EHM from the Ground Nucleon Structure Exploration in 12 GeV Era

- A unique combination of high luminosity (10^{38} $cm^{-2}s^{-1}$), duty cycle, and polarization capabilities make the **SBS facility at JLab** the most suitable in the world for studies of the nucleon elastic form factor at high Q^2 up to 15 GeV^2
- The **BONUS installation in the CLAS12** detector extends the capabilities in the studies of the F_2 DIS structure function off neutrons at large x_B and Q^2 above 5.0 GeV^2



- Provide strong constraints on the rate of the transition from fully dressed to pQCD quarks
- Further explore the relevance of di-quark correlations through the search for zero crossing in Q^2-evolution of d-quark contribution into Dirac nucleon elastic form factor

Shed light on the presence of di-quark correlations of spin-parity 0^+ and 1^+



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** **1.1-1.70** **1.6-2.00**	**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** **1.1-1.80**	**0.16-0.36** **0.4-1.8** **3.0-6.0** **0.4-1.0**	$d\sigma/d\Omega$ $d\sigma/d\Omega$, A_b,A_t,A_{bt} $d\sigma/d\Omega$ $d\sigma/d\Omega$
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** **0.70-5.4**	$d\sigma/d\Omega$ 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

Around 150,000 data points!

Almost full coverage of the final state hadron phase space

The measured observables from CLAS 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:

- **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 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). Argonne-Osaka

H. Kamano, JPS Conf. Proc. 13, 010012 (2017). Argonne-Osaka

M. Mai et al., Phys. Rev. C103, 065204 (2021) Julich-Bonn-Washington

M. Mai et al., Phys. Rev. C106, 015201 (2022) Julich-Bonn-Washington