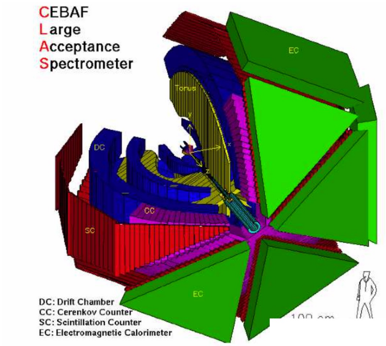
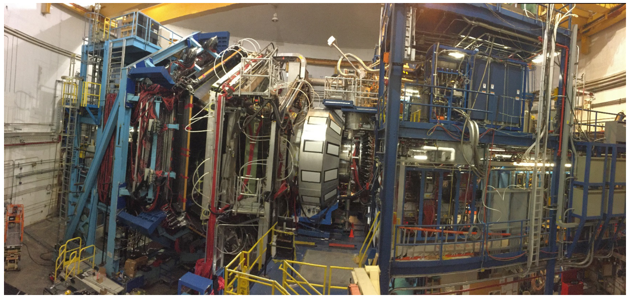
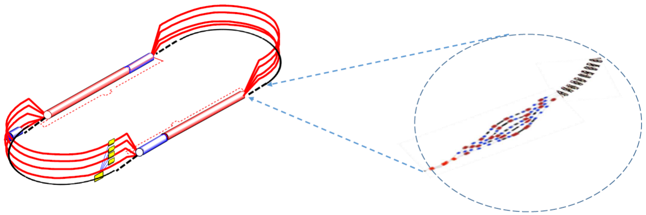
Insight into Emergence of Hadron Mass in the Exploration of N* Structure at JLab after Energy and Luminosity Increase

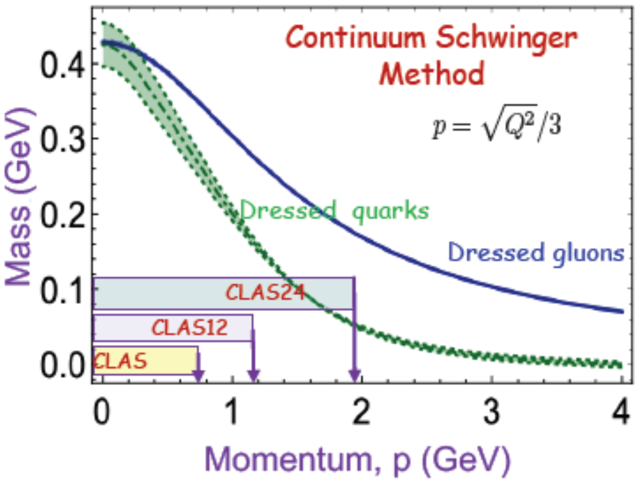




FFA concept for CEBAF energy upgrade:

- 5 additional recirculations in existing tunnel
- Use existing LINACs 5 more times each





- Concept on emergence of hadron mass (EHM) from QCD within continuum Schwinger function method (CSM)
- Gaining insight into EHM from ***combined*** studies of π/K and N/N* structure. Why is this needed?
- Evidence and limitations for gaining insight into EHM from experiments at JLab with 6/12 GeV beam
- Understanding EHM from the results on N* electrocouplings determined within Q^2–range up to 35 GeV^2

V.I. Mokeev
Jefferson Lab
(CLAS Collaboration)

Office of Science

Hadron Physics Opportunities with JLab Energy and Luminosity Upgrade

How do the Ground/Excited State Nucleon Masses Emerge?

Composition of the Nucleon Mass:

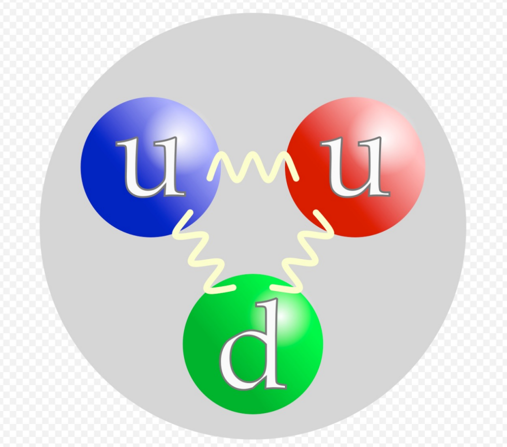
M_p, MeV (PDG20)

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



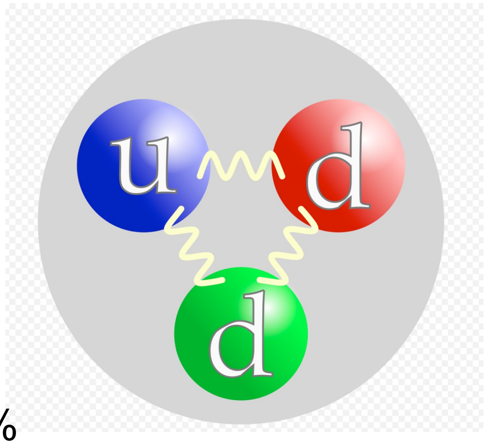
M_n, MeV (PDG20)

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

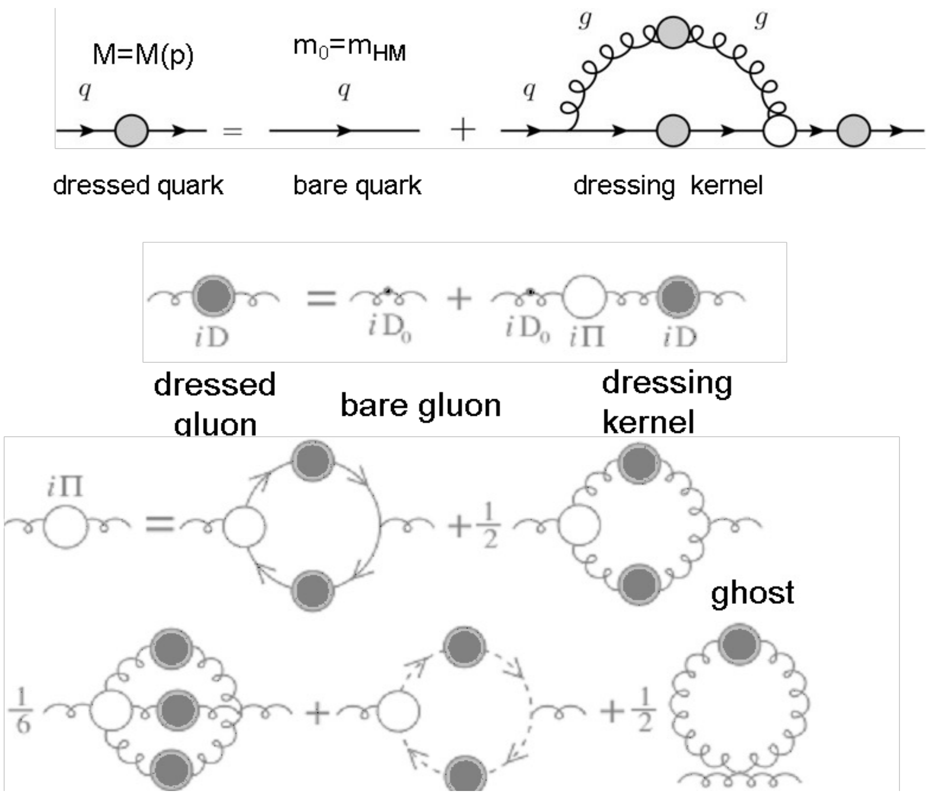


- **Higgs mechanism generates the masses of bare quarks**
- **Dominant part of nucleon mass is generated in processes other than the Higgs mechanism**

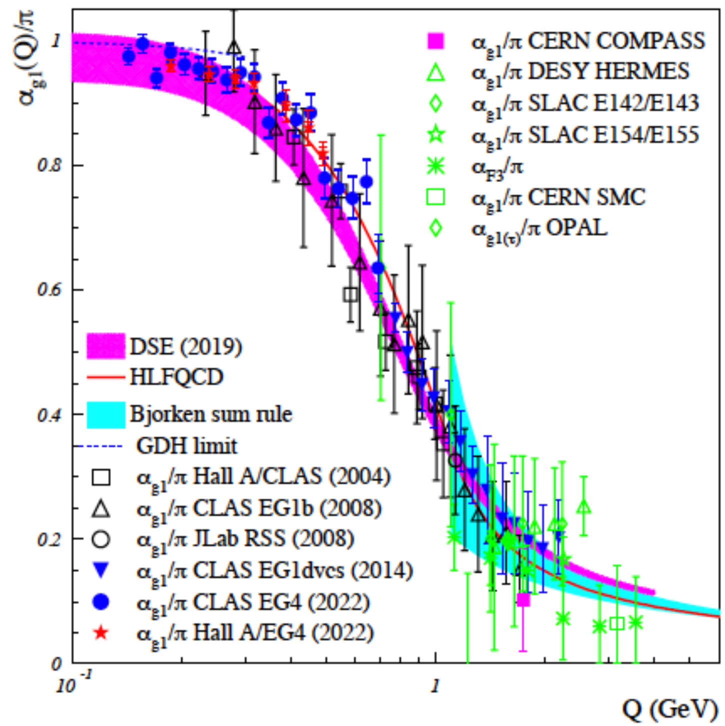
The Continuum Schwinger method (CSM) has conclusively demonstrated that the dominant part of hadron mass is generated by the strong interaction in the regime where the QCD running coupling becomes comparable with unity - the so-called strong QCD regime

Basics for Insight into EHM: CSM 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)

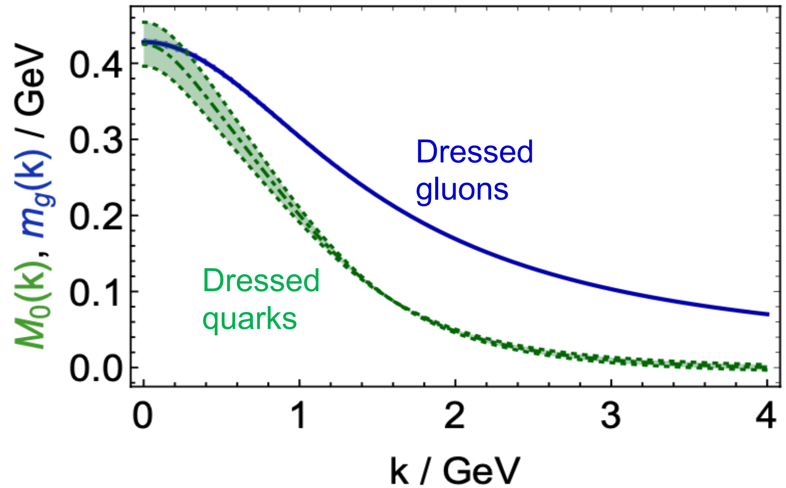


In the regime of the QCD running coupling comparable with unity, dressed quarks and gluons with distance (momentum) dependent masses emerge from QCD, as follows from the equations of the motion for the QCD fields depicted above.

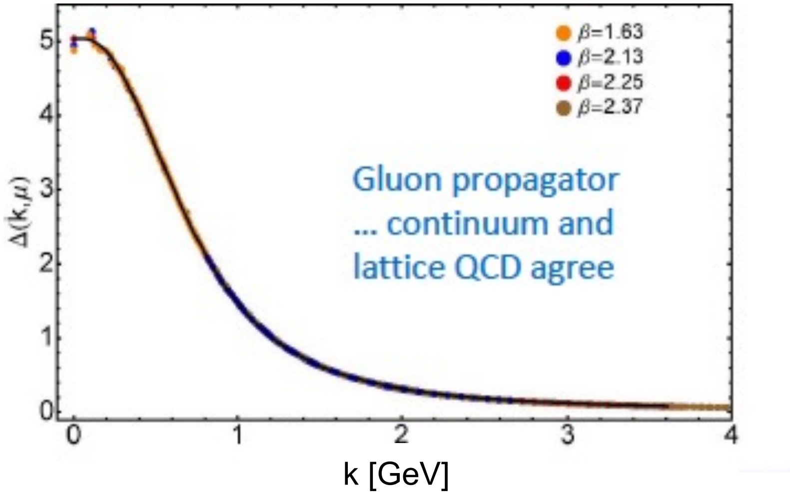
Basics for Insight into EHM: Continuum and Lattice QCD Synergy

- Express the fundamental feature: emergence of the quark and gluon masses even in the case of massless quarks in the chiral limit and massless QCD gluons
- Continuum QCD results are confirmed by LQCD
- Insight into EHM from data on hadron structure represents a challenge for experimental hadron physics

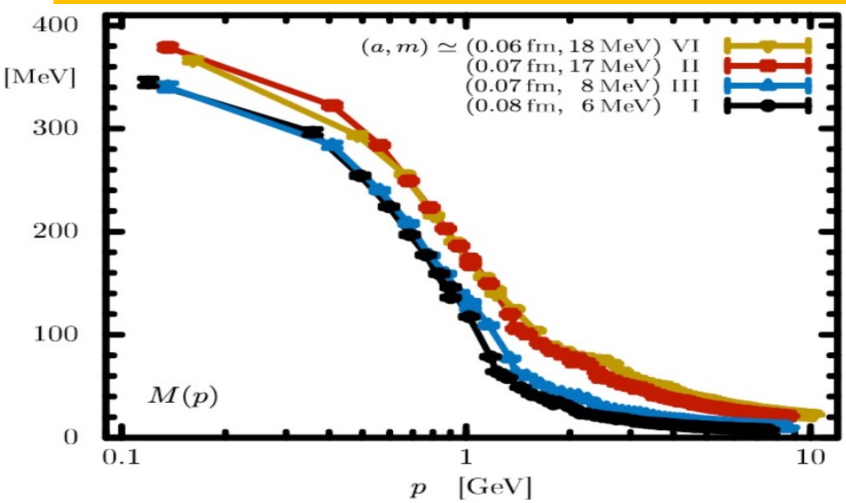
Dressed Quark/Gluon Masses (Continuum QCD)
C.D. Roberts, Symmetry 12, 1468 (2020)



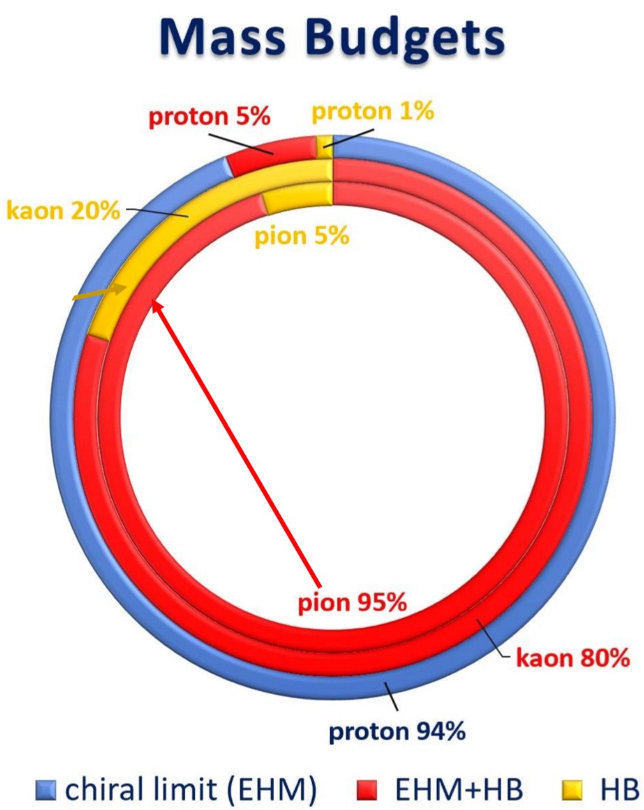
Inferred from QCD Lagrangian with only Λ_{QCD} parameter



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



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

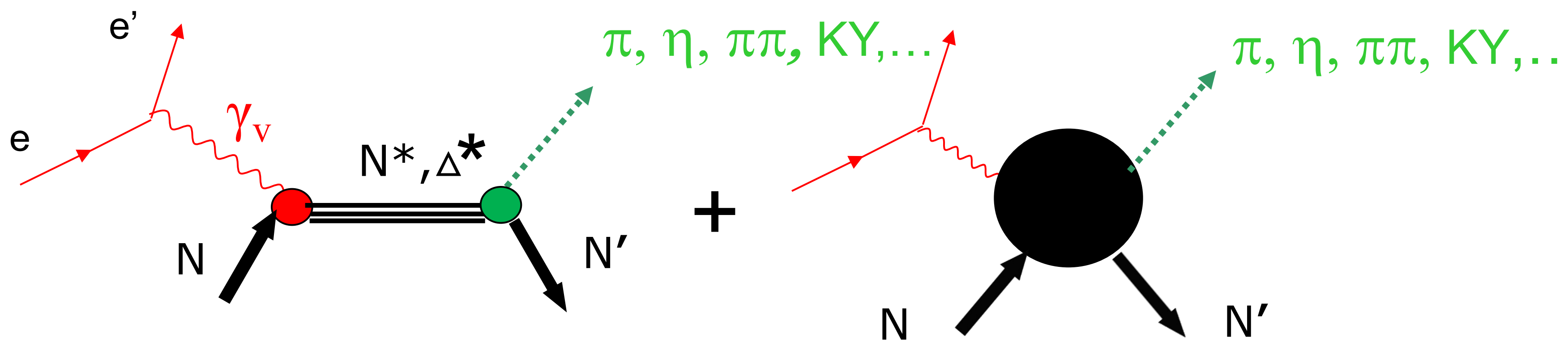


- Studies of π/K structure elucidate the interference between emergent and Higgs mechanisms in EHM
- Studies of ground/excited state nucleon structure allow us to explore the dressed quark mass function in a different environment where the sum of dressed quark masses is the dominant contribution to the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

- 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 and their Extraction from Exclusive 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 the $\gamma_{r,v}pN^*$ photo-/electrocouplings from different meson photo-/electroproduction channels allow us to validate reliable extraction of these quantities.**

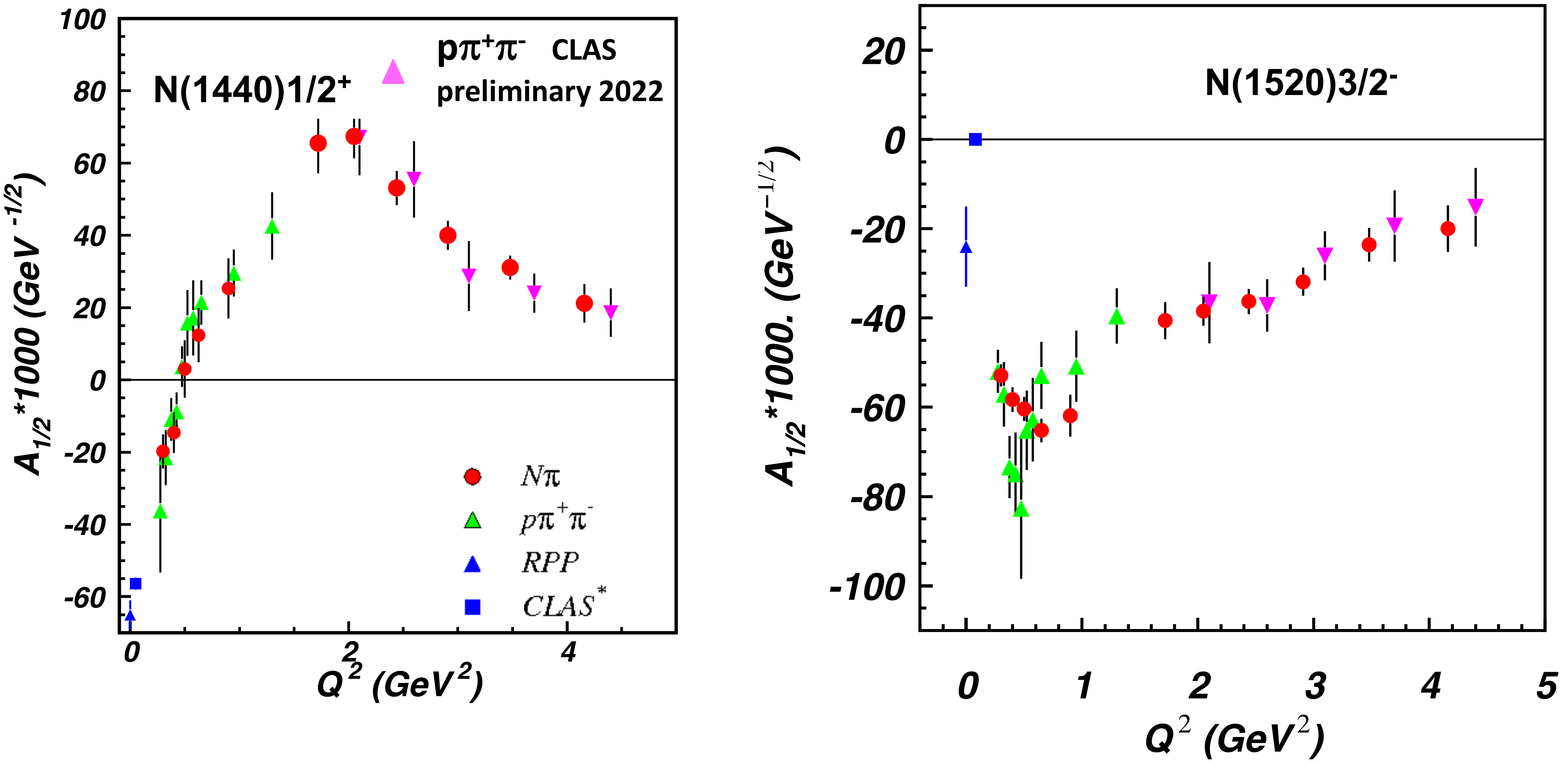
Nucleon Resonance Electrocouplings from Data On Exclusive Meson Electroproduction with CLAS

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

- The N* electroexcitation amplitudes ($\gamma_v pN^*$ electrocouplings) have become available in a broad range of $Q^2 < 5$ GeV^2
- In the mass range W < 1.6 GeV, the $\gamma_v pN^*$ electrocoupling were obtained from independent studies of πN, ηp, and $\pi^+\pi^- p$ electroproduction

Most 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

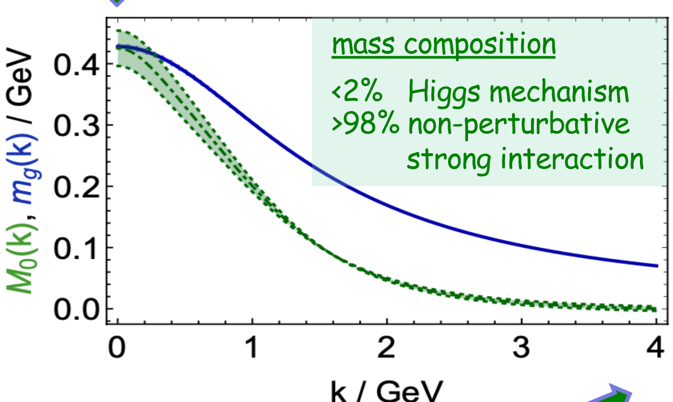


Consistent results on the N(1440)1/2$^+$ and N(1520)3/2$^-$ electrocouplings from independent studies of the two major πN and $\pi^+\pi^-$p electroproduction channels with different non-resonant contributions allow us to evaluate the systematic uncertainties of these quantities in a nearly model-independent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

Emergence of Hadron Mass: Concept from CSM vs. Available Experimental Results

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*

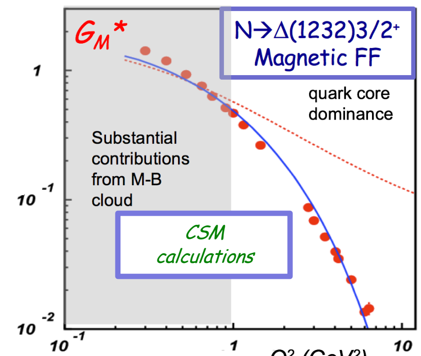
confinement regime:
- constituent quark mass



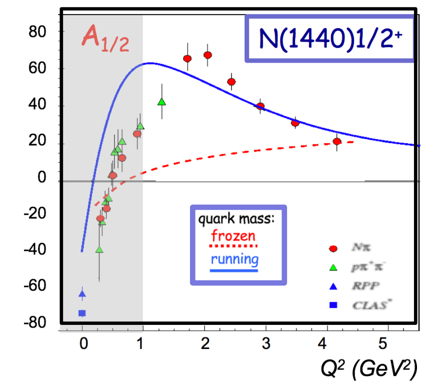
approaching bare quark Higgs mass

Dressed Quark/Gluon Masses from CSM
C.D. Roberts, Symmetry 12, 1468 (2020)

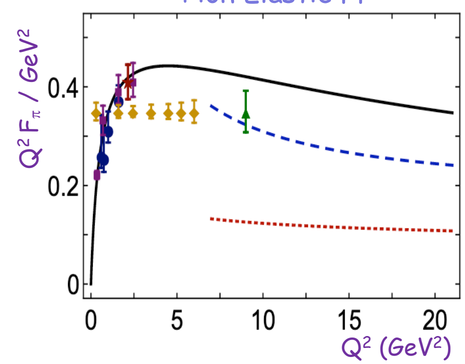
CLAS results vs. CSM expectations with running quark mass



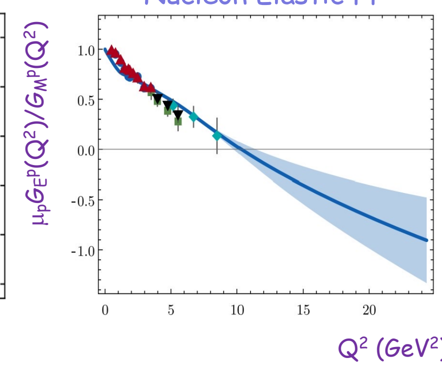
J. Segovia, PRL 115, 171801 (2015)



Pion Elastic FF

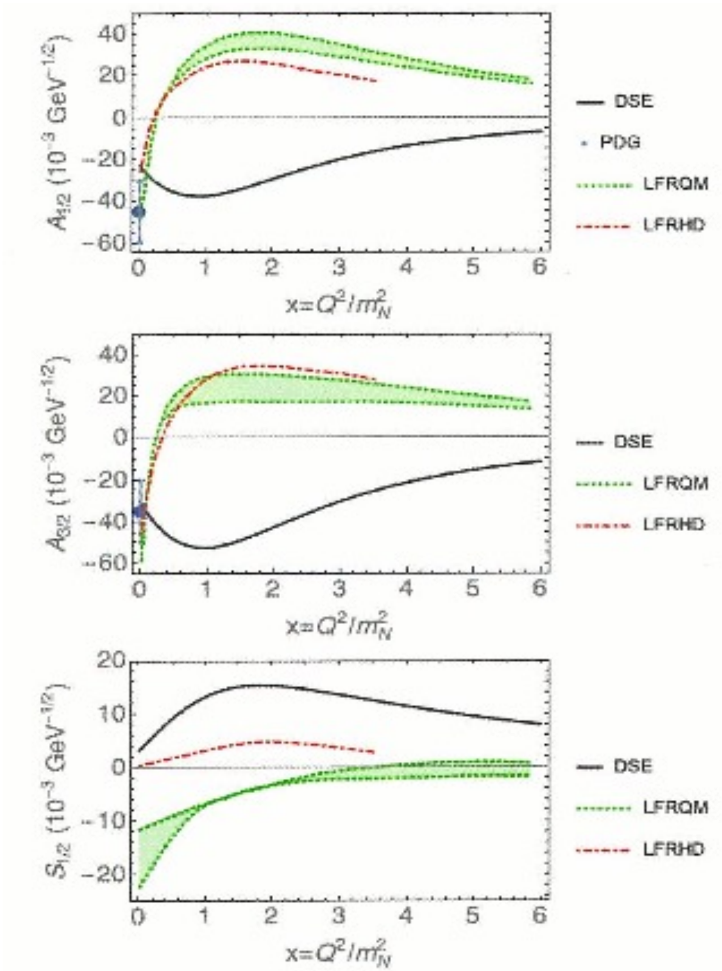


Nucleon Elastic FF



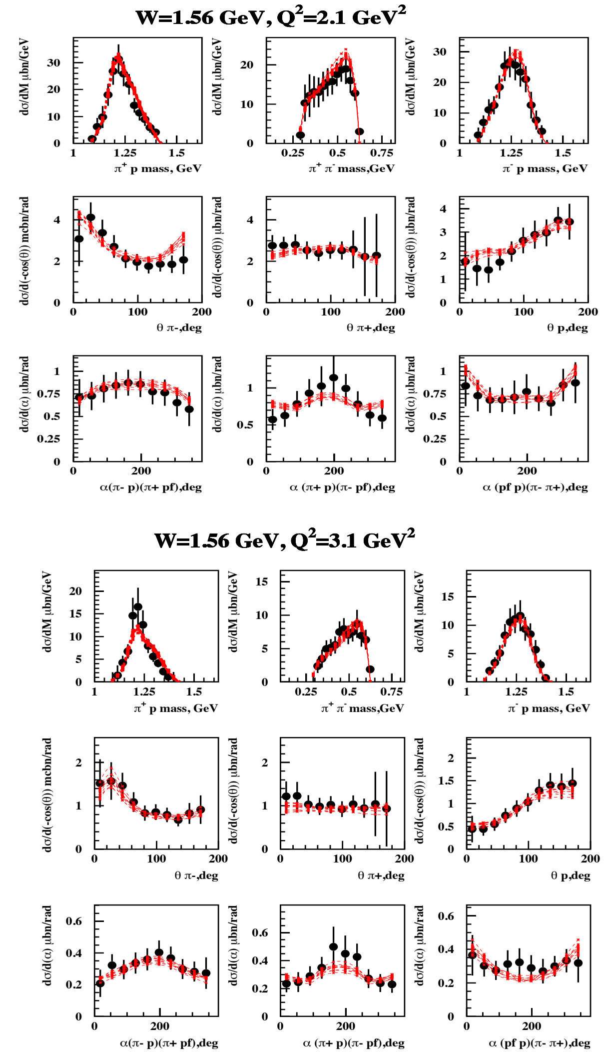
- Dressed quarks with dynamically generated masses represent active degrees of freedom in the structure of the pion, nucleon, and the Δ(1232)3/2⁺, N(1440)1/2⁺ resonances
- **Strong evidence for insight into EHM**

Electrocouplings of the Δ(1600)3/2$^+$: CSM Prediction vs. Data Determination

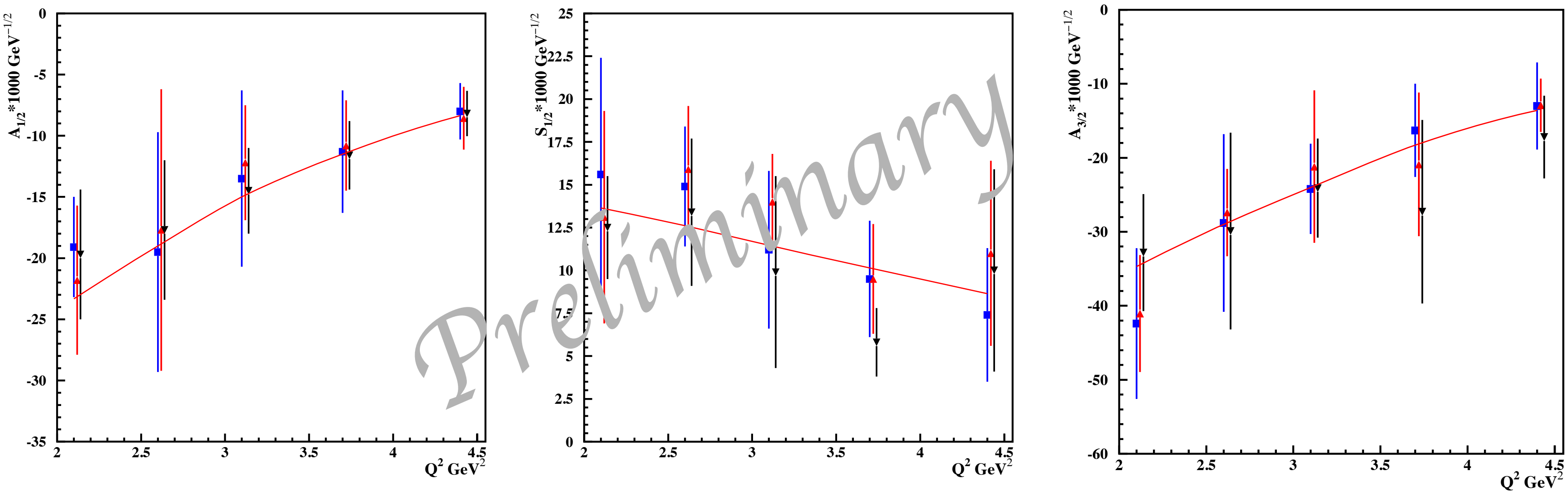


Parameter-free CSM predictions for Δ(1600)3/2$^+$ electrocouplings
Ya Lu et al., Phys. Rev. D 100, 034001 (2019)

Extraction of Δ(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



Electrocouplings of the Δ(1600)3/2⁺: CSM prediction vs. Data Determination



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

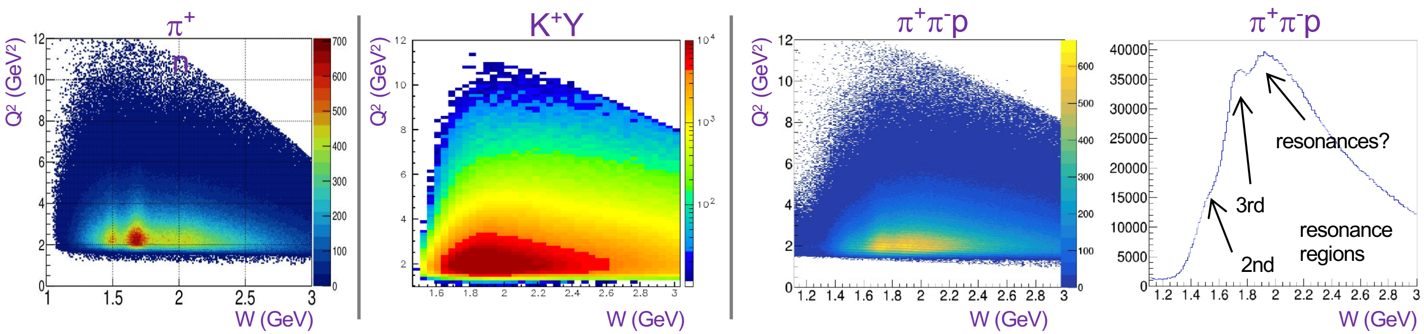
Electrocouplings from independent analyses of $\pi^+\pi^-p$ differential cross sections within three W-intervals, 1.46<W<1.56 GeV, 1.51<W<1.61 GeV, and 1.56<W<1.66 GeV for $2.0<Q^2<5.0$ GeV^2

CLAS results on Δ(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

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, $\pi\pi N$, 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			$K^+\Lambda$ & $K^+\Sigma^0$					$\pi^+\pi^-p$		
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*

Emergence of Hadron Mass from N* Studies with CLAS/CLAS12 and Expected with CLAS24

N* electroexcitation studies at JLab during 12 GeV era will address the critical questions:

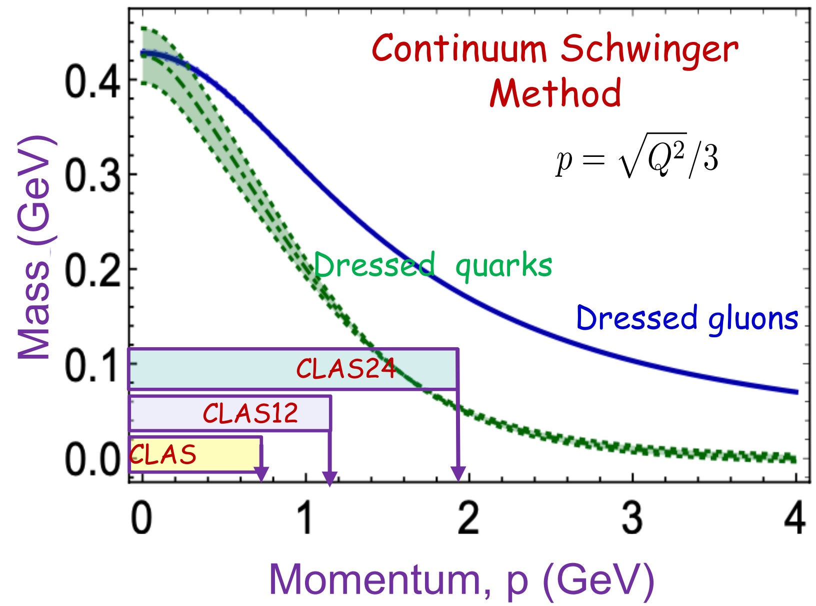
How is >98% of visible mass generated?

How EHM is related to Dynamical Chiral Symmetry Breaking?

(S.J, Brodsky et al., Int. J. Mod. Phys. Rev. E29, 2030006 (2020))

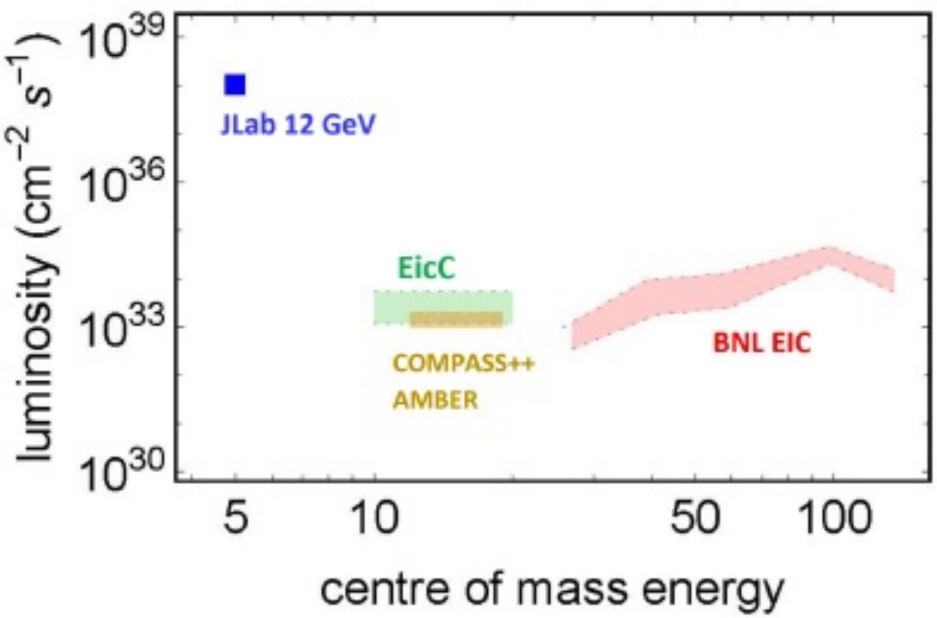
Mapping-out the dressed quark mass function from $\gamma_v pN^*$ electrocouplings of different spin-isospin flip, radial, and orbital excited nucleon states at $5<Q^2<12$ GeV^2 will increase knowledge on EHM and motivate efforts to determine $\gamma_v pN^*$ electrocouplings for Q^2 up to 35 GeV^2 to explore the full range of distances (quark momenta) where the dominant part of hadron mass is expected to be generated

	Q^2-coverage for $\gamma_v pN^*$ electrocoupling results	Accessible range of quark momenta p	Fraction of fully dressed quark mass generated at $p<p_{max}$
CLAS	<5.0 GeV^2	<0.8 GeV	15-20 %
CLAS12	<9.0-10.0 GeV^2	<1.0 GeV	40-50 %
CLAS24	<35.0 GeV^2	<2.0 GeV	>90 %



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

Energy and luminosity increase are needed in order to obtain information on the $\gamma_v pN^*$ electro-couplings 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



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 $Q^2>10\ GeV^2$

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

- Kinematic coverage in the resonance region for W<2.0 GeV with electron beam energy E_b=24 GeV, $\theta_{e\ max}=35^o$.

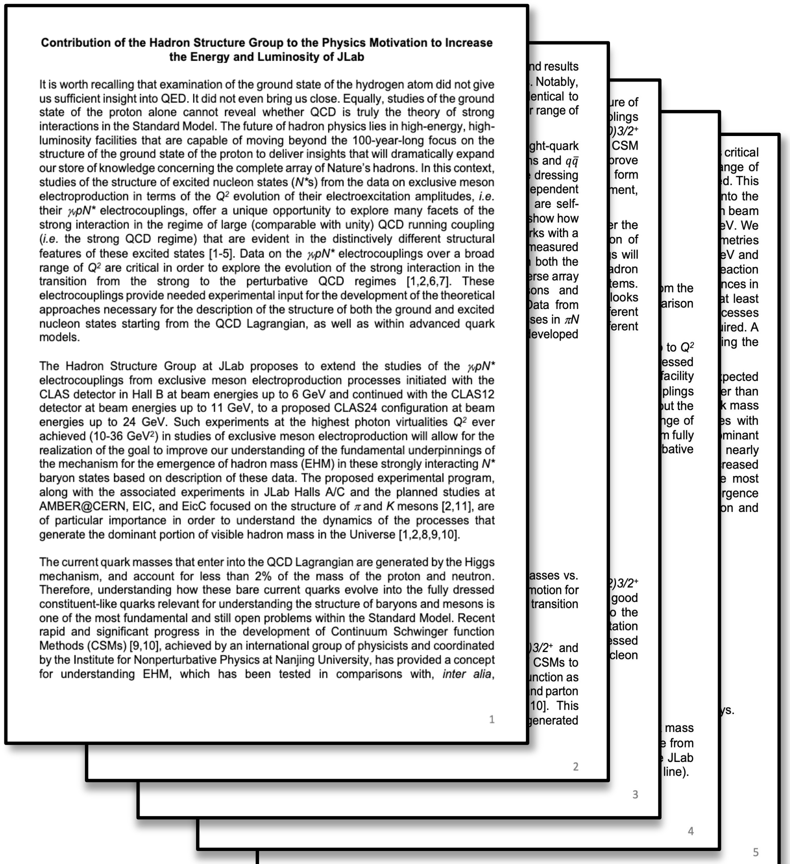
$$Q^2_{max} = \frac{2M_N E_b - W^2 + M_N^2}{(1 + \frac{M_N}{2E_b sin^2(\frac{\theta e}{2})})}$$

W, GeV	1.1	2.0
Q^2_{max}, GeV^2	36.7	34.4
P quark, GeV	2.02	1.96

- The coverage over Q^2 within the resonance region allows us to map out the momentum dependence of the dressed quark mass function within the range of p_{quark} < 2.0 GeV and observe how the dominant part of hadron mass emerges.

- Luminosity ~$10^{36}\ cm^{-2}s^{-1}$ may be sufficient for the extraction of the $\gamma_v pN^*$ electrocouplings if the rate of exclusive cross section fall-off with Q^2 at Q^2> 10 GeV^2 is the same as at Q^2<10 GeV^2 and the (resonant)/(background) ratio does not deteriorate.

Hadron Structure Studies with CLAS24


Contribution of the Hadron Structure Group to the Physics Motivation to Increase the Energy and Luminosity of JLab

It is worth recalling that examination of the ground state of the hydrogen atom did not give us sufficient insight into QED. It did not even bring us close. Equally, studies of the ground state of the proton alone cannot reveal whether QCD is truly the theory of strong interactions in the Standard Model. The future of hadron physics lies in high-energy, high-luminosity facilities that are capable of moving beyond the 100-year-long focus on the structure of the ground state of the proton to deliver insights that will dramatically expand our store of knowledge concerning the complete array of Nature's hadrons. In this context, studies of the structure of excited nucleon states (N^*s) from the data on exclusive meson electroproduction in terms of the Q^2 evolution of their electroexcitation amplitudes, *i.e.* their $\gamma_v pN^*$ electrocouplings, offer a unique opportunity to explore many facets of the strong interaction in the regime of large (comparable with unity) QCD running coupling (*i.e.* the strong QCD regime) that are evident in the distinctively different structural features of these excited states [1-5]. Data on the $\gamma_v pN^*$ electrocouplings over a broad range of Q^2 are critical in order to explore the evolution of the strong interaction in the transition from the strong to the perturbative QCD regimes [1,2,6,7]. These electrocouplings provide needed experimental input for the development of the theoretical approaches necessary for the description of the structure of both the ground and excited nucleon states starting from the QCD Lagrangian, as well as within advanced quark models.

The Hadron Structure Group at JLab proposes to extend the studies of the $\gamma_v pN^*$ electrocouplings from exclusive meson electroproduction processes initiated with the CLAS detector in Hall B at beam energies up to 6 GeV and continued with the CLAS12 detector at beam energies up to 11 GeV, to a proposed CLAS24 configuration at beam energies up to 24 GeV. Such experiments at the highest photon virtualities Q^2 ever achieved (10-36 GeV^2) in studies of exclusive meson electroproduction will allow for the realization of the goal to improve our understanding of the fundamental underpinnings of the mechanism for the emergence of hadron mass (EHM) in these strongly interacting N^* baryon states based on description of these data. The proposed experimental program, along with the associated experiments in JLab Halls A/C and the planned studies at AMBER@CERN, EIC, and EicC focused on the structure of π and K mesons [2,11], are of particular importance in order to understand the dynamics of the processes that generate the dominant portion of visible hadron mass in the Universe [1,2,8,9,10].

The current quark masses that enter into the QCD Lagrangian are generated by the Higgs mechanism, and account for less than 2% of the mass of the proton and neutron. Therefore, understanding how these bare current quarks evolve into the fully dressed constituent-like quarks relevant for understanding the structure of baryons and mesons is one of the most fundamental and still open problems within the Standard Model. Recent rapid and significant progress in the development of Continuum Schwinger function Methods (CSMs) [9,10], achieved by an international group of physicists and coordinated by the Institute for Nonperturbative Physics at Nanjing University, has provided a concept for understanding EHM, which has been tested in comparisons with, *inter alia*,

1

Hadron Structure Group in Hall B developing physics case to support CLAS24 upgrade

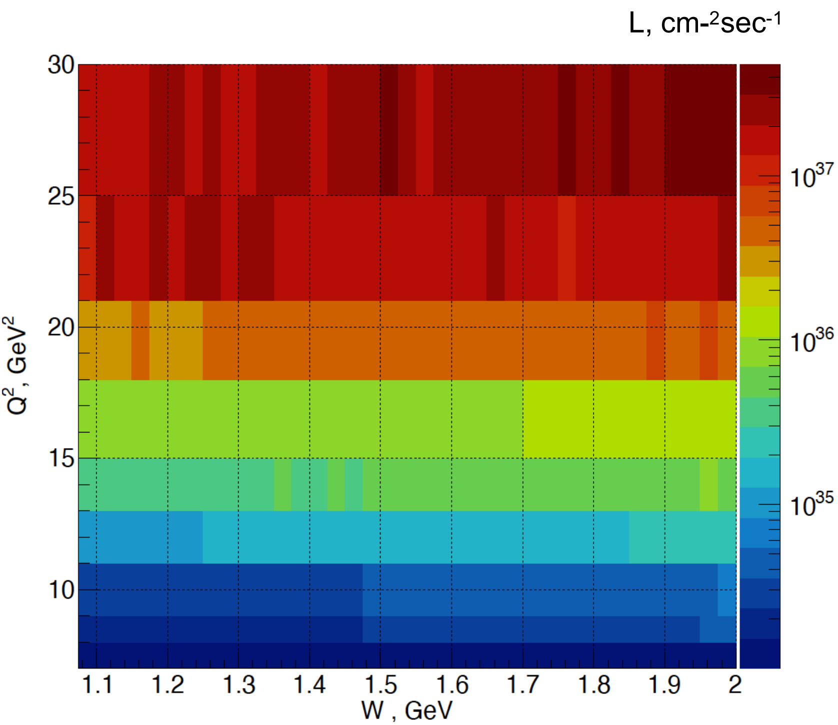
List of Participating Institutions:

- 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 and affiliated institutes
- Tubingen University
- Tomsk State University and Tomsk Polytechnic University
- James Madison University
- George Washington University

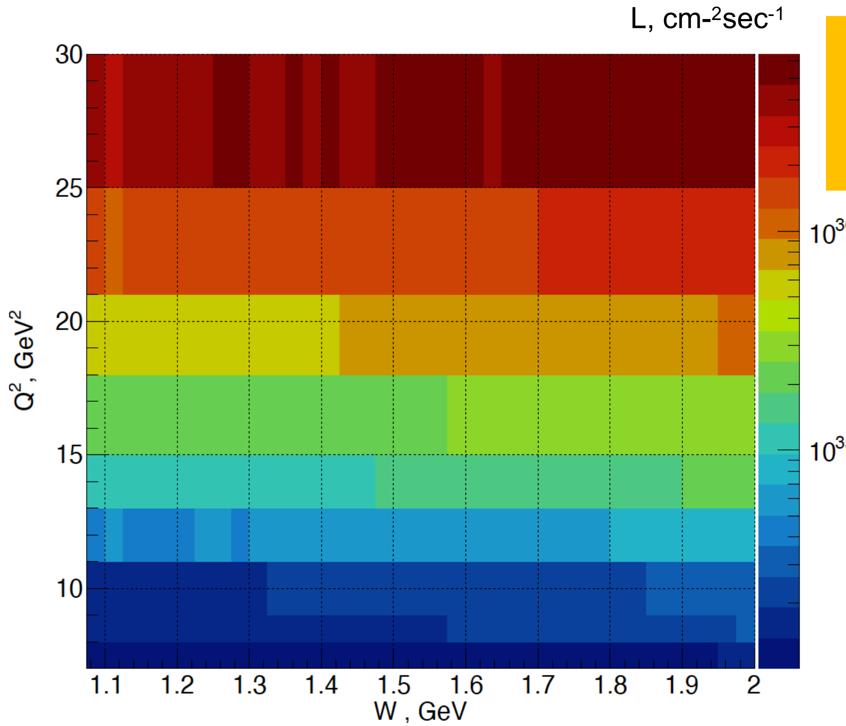
https://userweb.jlab.org/~carman/clas24

Luminosity to Determine $\gamma_v pN^*$ Electrocouplings at Q^2>10 GeV^2 from $N\pi$ Electroproduction

M.Davydov,
E. Isupov,
Moscow State
U.



M1+ $\sim 1/Q^6$ others $\sim 1/Q^4$



M1+ $\sim 1/Q^6$ others $\sim 1/Q^2$

- Luminosities needed for extraction of $\gamma_v pN^*$ electrocouplings from $N\pi$ electroproduction at Q^2>10 GeV^2 were evaluated in each bin of (W,Q^2) as:

$$L(W,Q^2), = 10^{34}\ cm^{-2}sec^{-1}\ Y(W,Q^2{}_{current})/Y(W,Q^2=5.0\ GeV^2)\quad (1),$$

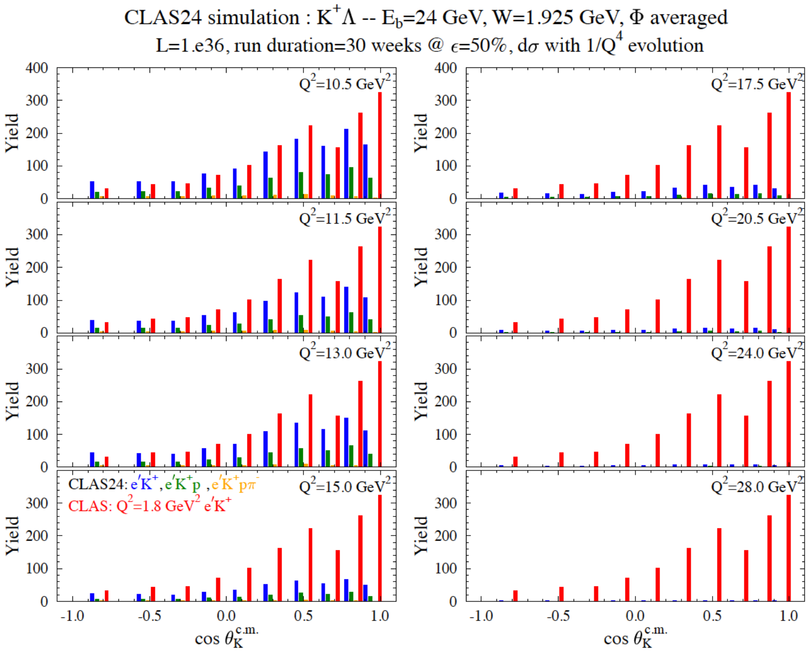
assuming that statistics comparable with those achieved in the measurements with CLAS in the bin of (W,Q^2 =5 GeV^2) at luminosity 10^{34} $cm^{-2}sec^{-1}$ will be sufficient

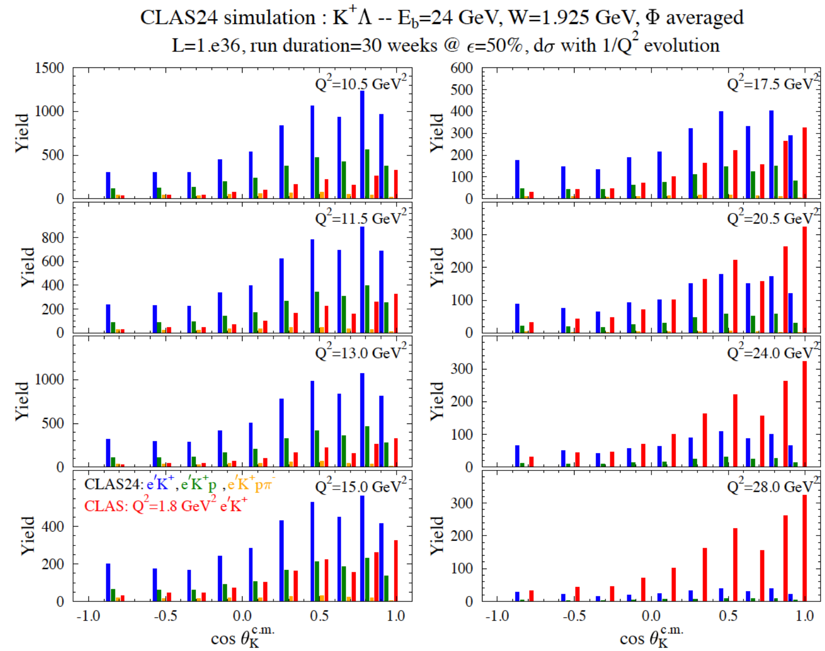
- The ratio $Y(W,Q^2{}_{current})/Y(W,Q^2 =5.0\ GeV^2)$ was obtained in MC simulation for E_{beam}=24 GeV with $N\pi$ cross sections computed from the MAID07 multipoles at Q^2 =5.0 GeV^2, extrapolated into the range of Q^2>10 GeV^2 as the accepted event ratio computed for CLAS12.

$\gamma_v pN^*$ electrocouplings can be determined up to Q^2_{max} in the range from 18 GeV^2 to 22 GeV^2 where the required luminosity remains below ~10^{36} $cm^{-2}sec^{-1}$

$\gamma_v pN^*$ Electrocouplings at Q^2>10 GeV^2 from $K\Lambda$ Channel

D.S. Carman, Jefferson Lab





Yields of $K\Lambda$ events in the bins of (W,Q^2,cos θ_K^{cm}) were evaluated in MC simulation by employing 2-fold differential cross sections from the CLAS measurements at Q^2<4 GeV^2 and extrapolated into the range of Q^2>10 GeV^2 as $1/Q^4$ (left panel), $1/Q^2$ (right panel)

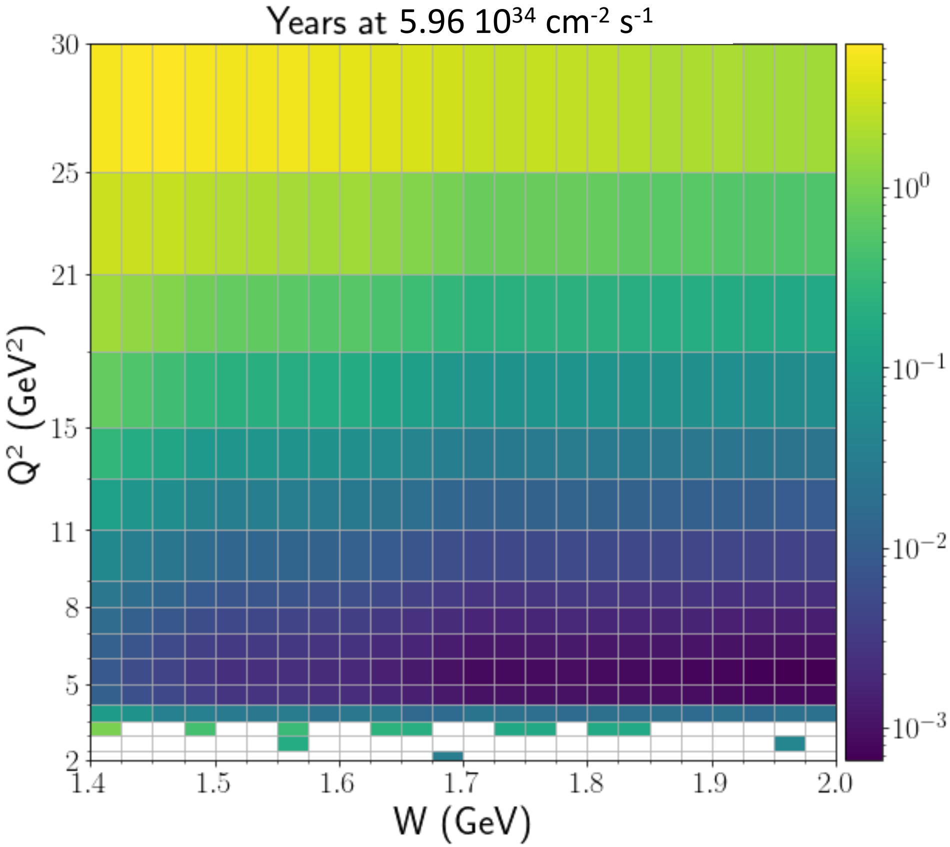
$\gamma_v pN^*$ electrocouplings can be determined up to Q^2_{max} in the range from 14 GeV^2 < Q^2 < 20 GeV^2, where the projected yields remains comparable with those achieved in the CLAS measurements

Beam Time Needs for Exclusive $p\pi^+\pi^-$

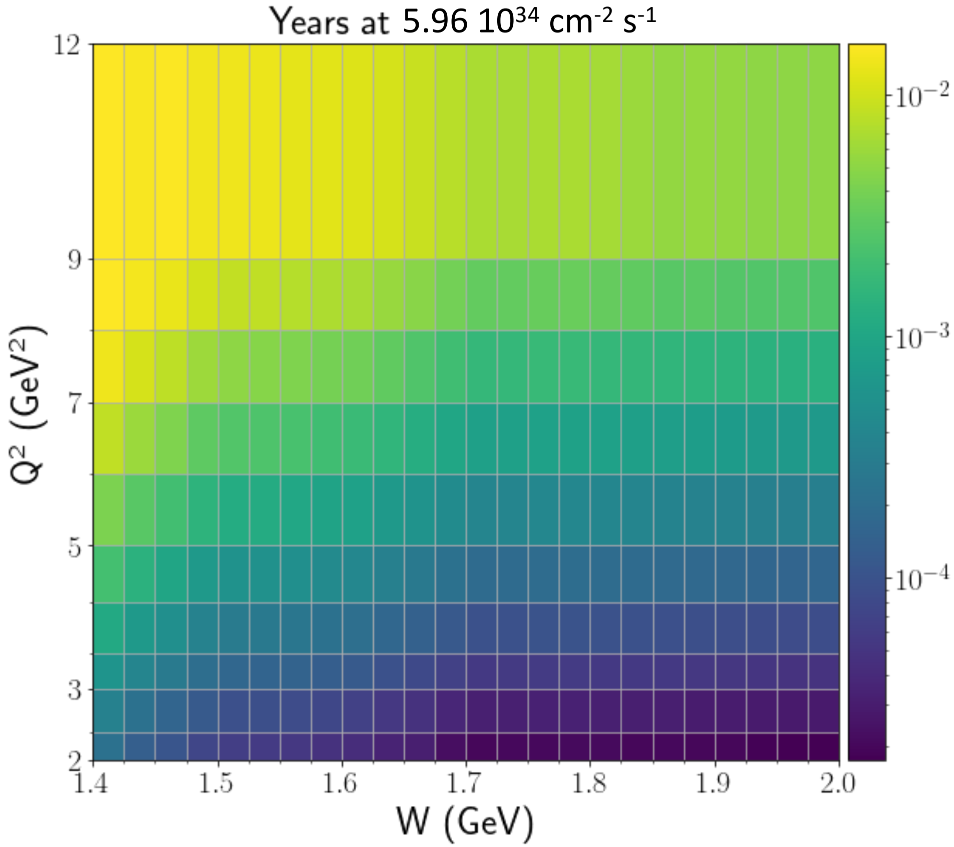
K. Neupane, R.W. Gothe - USC

Based on RG-A fall 2018 Luminosity of 5.96 10^{34} cm^{-2} s^{-1} at 45 nA

Simulated at 24 GeV Beam Energy



Simulated at 10.6 GeV Beam Energy



Implementing all analysis cuts (3/2), Golden Run Selection (3), PAC Days (2)

➡ 6 (12) years at 5.96 10^{34} cm^{-2} s^{-1} or 4 (8) month at 10^{36} cm^{-2} s^{-1}

Conclusions and Outlook

- CSM paradigm for EHM makes a broad array of predictions. Those for N* structure in terms of the Q^2-evolution of the $\gamma_v pN^*$ electrocoupling are worth testing by confronting the CSM predictions obtained with the same dressed quark mass function against the experimental results determined from exclusive meson electroproduction data.

- A good description of the $\Delta(1232)3/2^+$ and $N(1440)1/2^+$ electroexcitation amplitudes *achieved within CSM approach starting from the QCD Lagrangian with the same dressed quark mass function* as used in the successful evaluations of the ground state nucleon electromagnetic/axial and pion form factors, and the pion PDF, demonstrated the capability for gaining insight into EHM.

- The CSM parameter-free predictions on the $\Delta(1600)3/2^+$ electrocouplings have been confirmed by the first and still preliminary results on the electrocouplings of this state obtained from $\pi^+\pi^-p$ electroproduction data solidifying evidence for gaining insight into the dressed quark mass function and, consequently, into EHM from the studies of $\gamma_v pN^*$ electrocouplings.

- Increase of the CEBAF beam energy up to 24 GeV and the upgrade of the detector capabilities to measure electroproduction events within ~4π acceptance at ~10^{36}cm^{-2}sec^{-1} will make it possible to determine the electrocouplings of prominent N* states at Q^2 from 10 GeV^2 to 20 GeV^2. Analyses of the results on Q^2-evolution of $\gamma_v pN^*$ electrocouplings at Q^2<20 GeV^2 will allow us to explore nearly entire range of distances where the dominant part of hadron mass is expected to be generated in the transition from the sQCD to pQCD regimes.

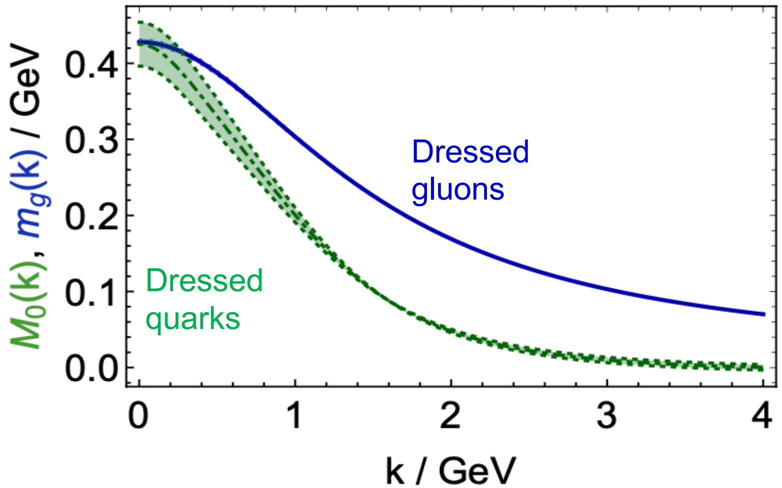
- Confirmation of the CSM predictions on the Q^2-evolution of the $\gamma_v pN^*$ electrocouplings of nucleon resonances of different structure obtained with the same dressed quark mass function by the experimental results within the range of Q^2 up to 20 GeV^2 will provide the sound evidence for understanding how the dominant part of hadron mass and the N* structructure emerge from QCD and will make JLab@24 GeV the unique and ultimate QCD-facility at the luminosity frontier.

Back up

Basics for Insight into EHM: Continuum and Lattice QCD Synergy

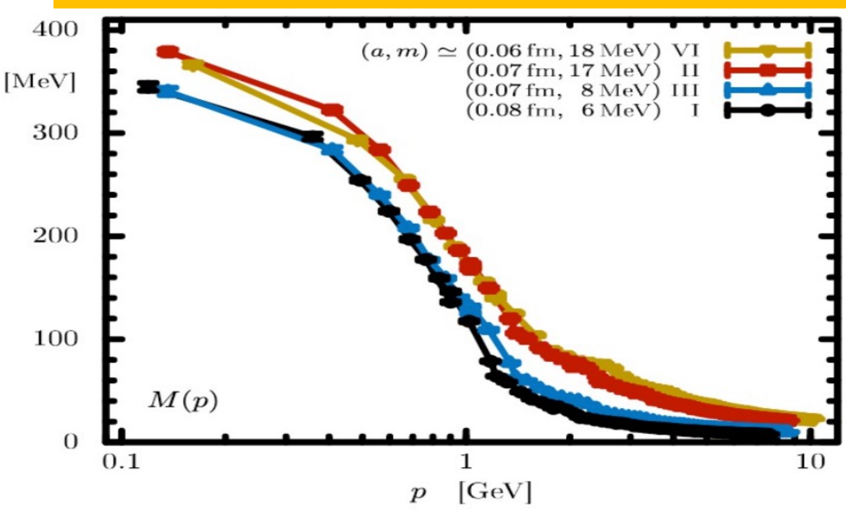
- Dressed quark/gluon masses converge at the complete QCD mass scale of 0.43(1) GeV - value impacted by Higgs mechanism
- Express the fundamental feature: emergence of the quark and gluon masses even in the case of massless quarks in the chiral limit and massless QCD gluons
- Continuum QCD results get support from LQCD
- Insight into dressed quark mass function from data on hadron structure represents a challenge for experimental hadron physics

Dressed Quark/Gluon Masses (continuum QCD)
C.D. Roberts, Symmetry 12, 1468 (2020)

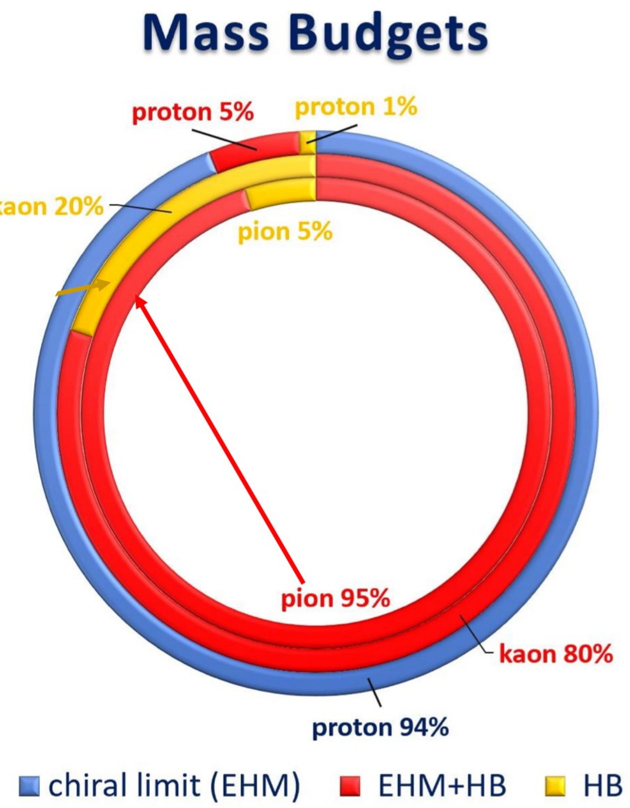


Inferred from QCD Lagrangian with only Λ_{QCD} parameter

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



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

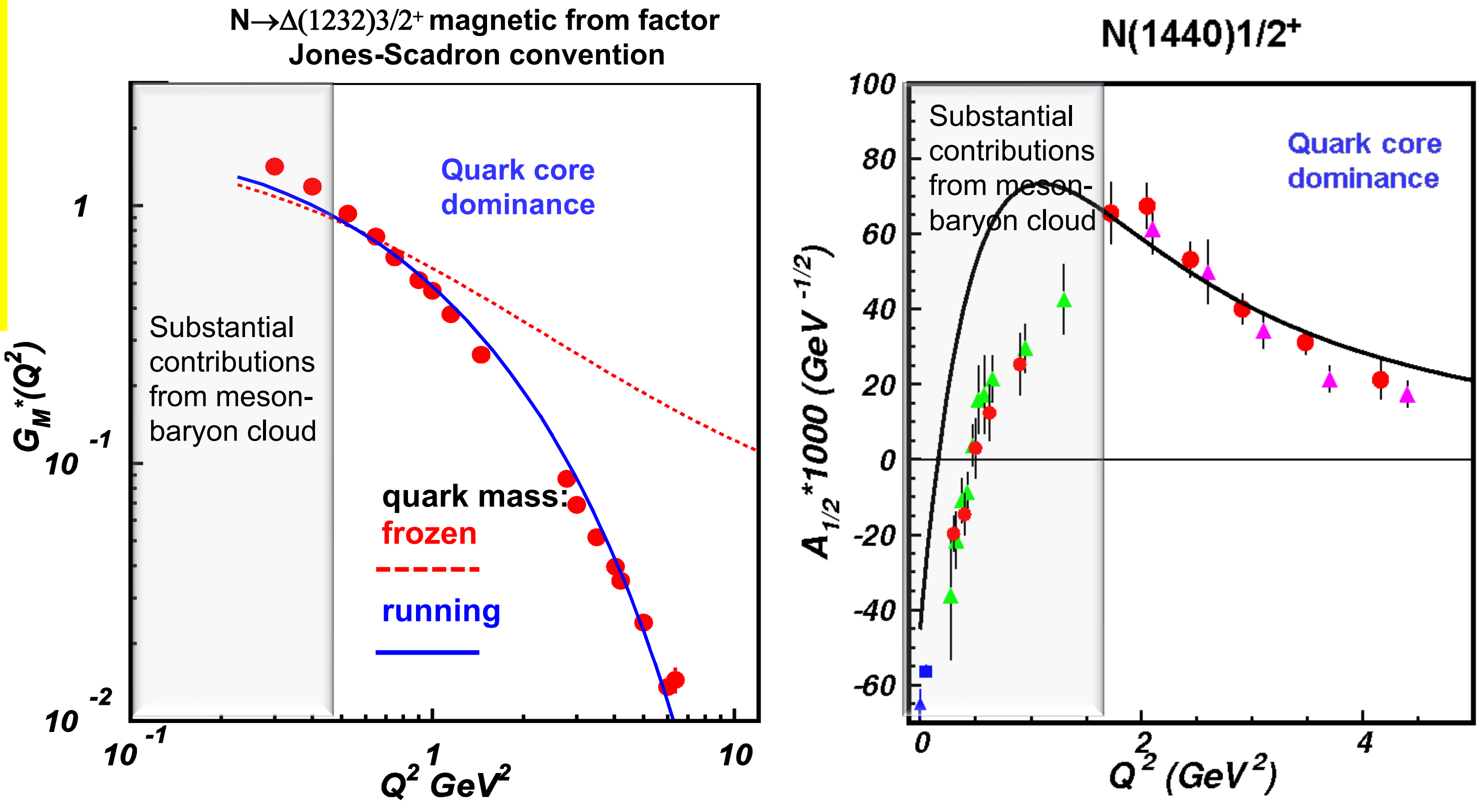


- Studies of the ground and excited state nucleon structure allow us to explore the dressed quark mass function in a different environment where the sum of dressed quark masses is the dominant contribution into the physical masses of the ground and excited states of the nucleon

- Consistent results on the momentum dependence of the dressed quark mass function from independent studies of the pseudo-scalar mesons and the ground and excited state nucleon structure are of particular importance for the validation of insight into EHM.

Insight to EHM From Resonance Electrocouplings

<u>Dyson-Schwinger Equations (DSE):</u>
- J. Segovia et al., PRL 115, 171801 (2015)
- J. Segovia et al., Few Body Syst. 55, 1185 (2014)

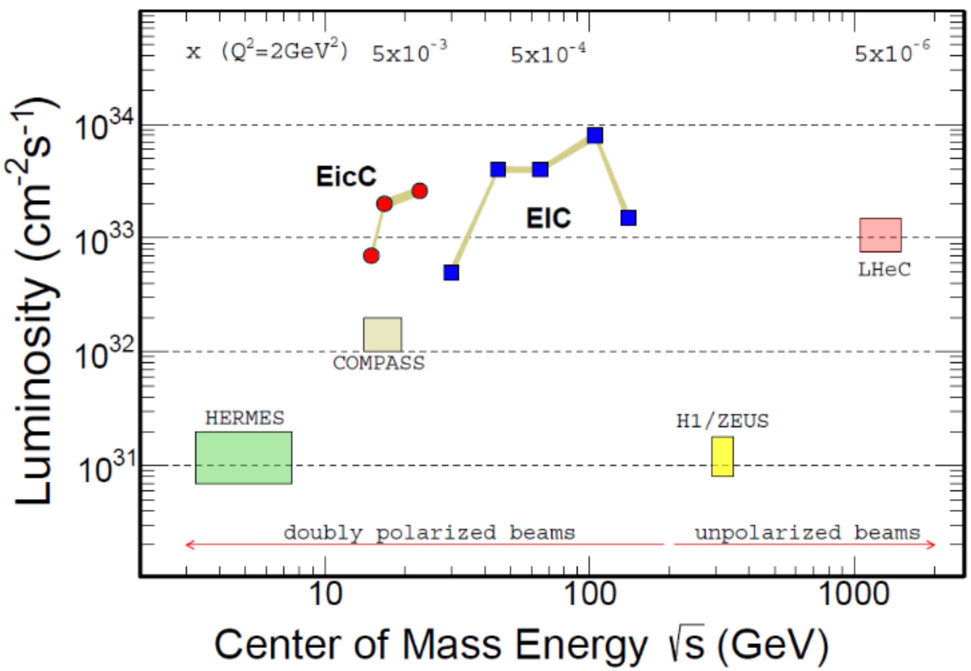


Good data description at Q^2>2.0 GeV^2 achieved with <u>the same dressed quark mass function</u> for the ground pion/nucleon and two excited nucleon states of distinctively different structure validates the continuum QCD results on the momentum dependence of the dressed quark mass. $\gamma_v pN^*$ electrocoupling data shed light on the strong QCD dynamics underlying hadron mass generation.

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

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

Energy and luminosity increase up to $>10^{36}\ cm^{-2}s^{-1}$ 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



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 $Q^2>10\ GeV^2$

Conclusions and Outlook

- **Resolving the most significant open problem in the Standard model on the EHM will make JLab@24 GeV the unique and ultimate QCD-facility at the luminosity frontier with significant contribution into achieving this objective from the studies of the structure of the excited state of the nucleon from the data of experiments with electromagnetic probes (see details in Contribution of the Hadron Structure Group to the Physics Motivation to Increase the Energy and Luminosity of JLab,** https://userweb.jlab.org/~carman/clas24/CLAS24-NstarStructure.pdf**)**