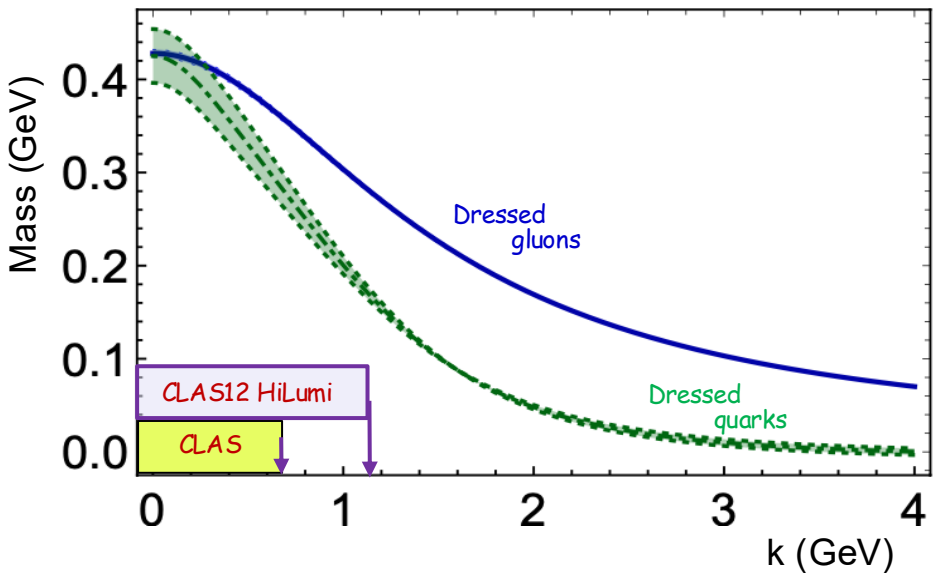
Physics Motivation for Increase of the CLAS12 Luminosity Across a Large Acceptance to Explore the Emergence of Hadron Mass and N* Structure



Continuum Schwinger Method (CSM) Concept on Emergence of Hadron Mass (EHM)

P. Achenbach, D.S. Carman, R.W. Gothe, K. Joo, V.I. Mokeev, and C.D. Roberts, Symmetry, 17, 1106 (2025)

M. Ding, C.D. Roberts, and S.M. Schmidt, Particles 6, 57 (2023)

Other QCD-connected theory approaches and quark models are encouraged.

- The dominant part of N/N* masses (94%-98%) is generated by strong interactions between dressed gluons and quarks. EHM is encoded in the evolution of the dressed quark/gluon masses and QCD running coupling α_s with momenta/distances.
- The successful description of pion and nucleon elastic EM form factors and $\gamma_v pN^*$ electrocouplings measured with CLAS at $Q^2 < 5$ GeV^2, within the CSM framework enables exploration of EHM across a range of distance scales over which ~30% of the hadron mass is generated.
- Available CLAS12 luminosity offers extension of Q^2 coverage for $\gamma_v pN^*$ electrocouplings to $Q^2 <$ 8-10 GeV^2 where ~50% of hadron mass emerges.

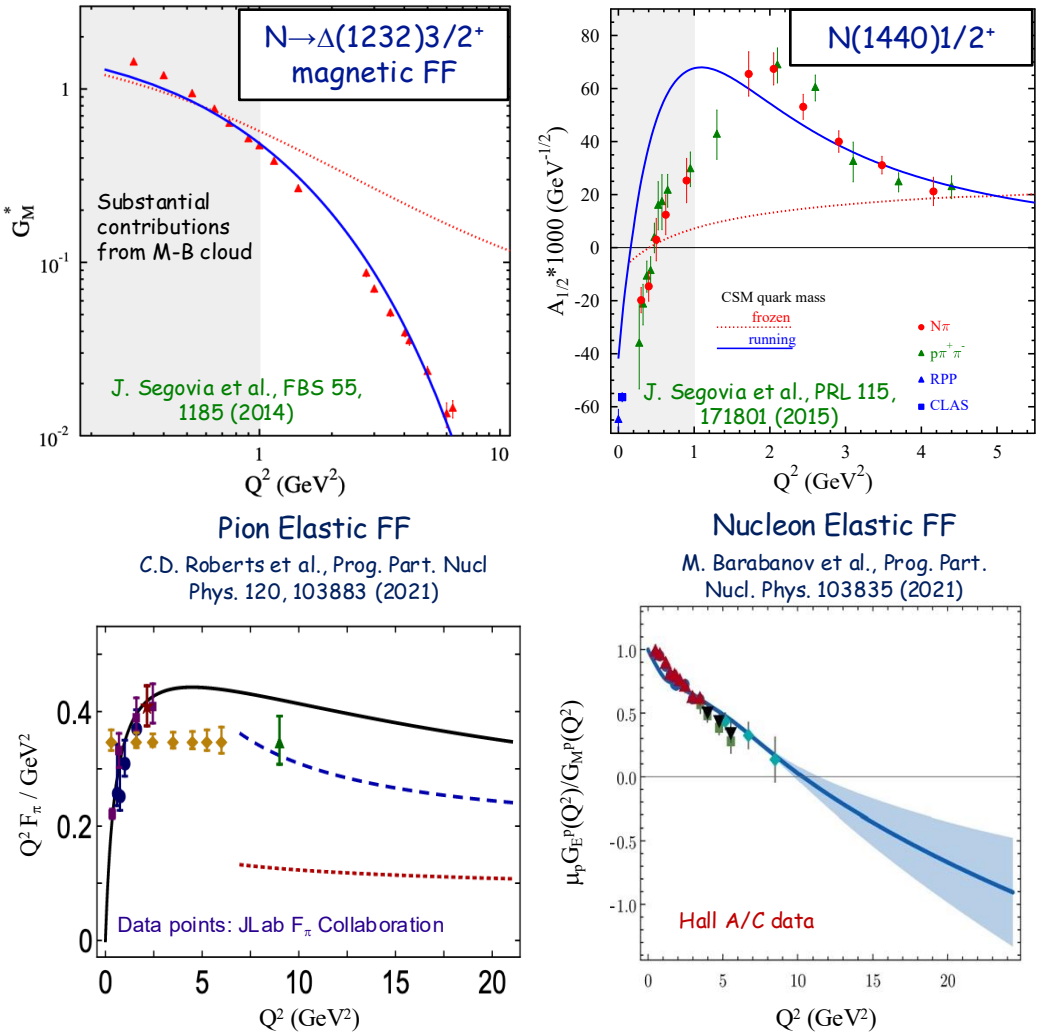
Insight into Dressed Quark Mass Function from Experimental Results

- A successful description of the pion and nucleon elastic FFs and the electrocouplings of the $\Delta(1232)3/2^+$ and $N(1440)1/2^+$ has been achieved in CSM *with the same deduced from QCD Lagrangian dressed quark/gluon mass functions*.

- Strong evidence for insight into momentum dependence of dressed quark mass.

- CLAS results on $N(1520)3/2^-$, $\Delta(1600)3/2^+$, and $\Delta(1700)3/2^-$ electrocouplings confirmed the CSM prediction across $Q^2>2$ GeV^2, solidifying evidence for insight into dressed quark mass function and, consequently, into EHM from the $\gamma_v pN^*$ electrocouplings.

CLAS/Hall A/C results vs. CSM expectations

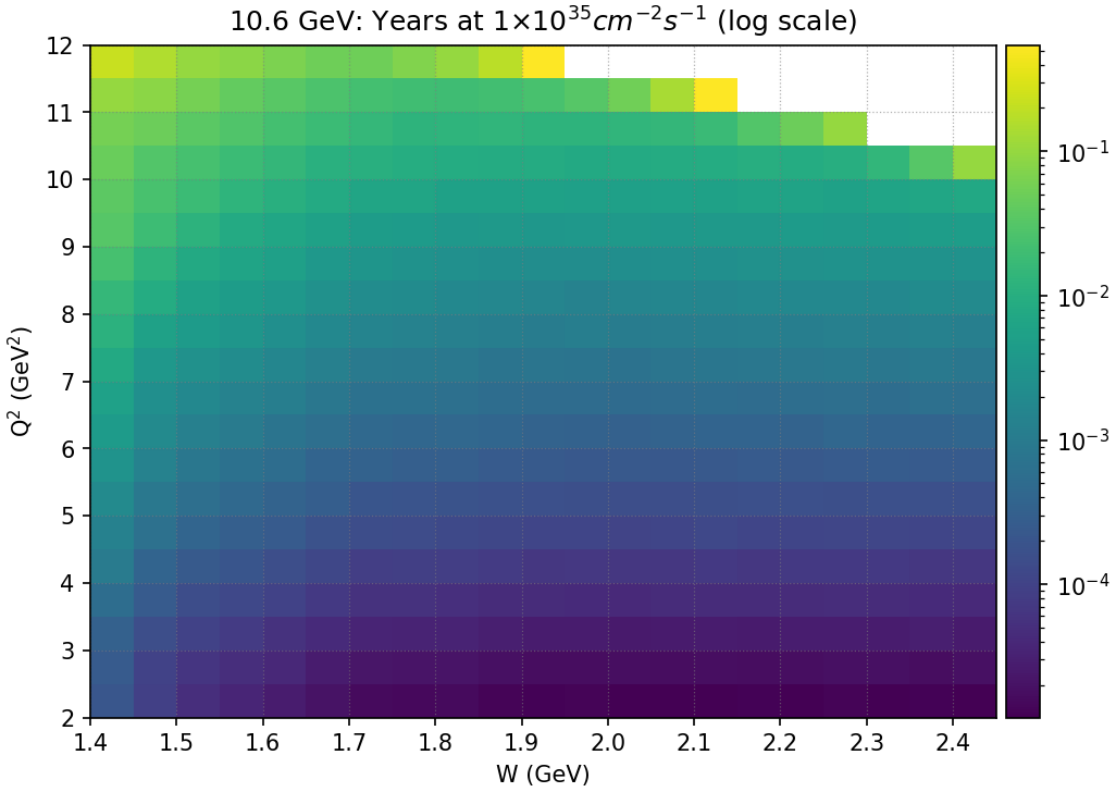


One of the most important achievements in hadron physics of the last decade in synergistic efforts between experiment, phenomenology, and theory.

Extension of Q^2-Coverage for $\gamma_v pN^*$ Electrocouplings After Increase of CLAS12 Luminosity

Simulation of $\pi^+\pi^-p$ Electroproduction

Beam time (in years) needed for sufficient statistics vs. bins in (Q^2,W) to extract $\gamma_v pN^*$ electrocouplings



R.W. Gothe, A. Osmond (USC)

Rate estimates for the accepted events using TWOPEG EG with CLAS12 (eff*acc) employing event selection as:
K. Neupane et al. (CLAS Collaboration) arXiv:2609.19395, submitted to PRC

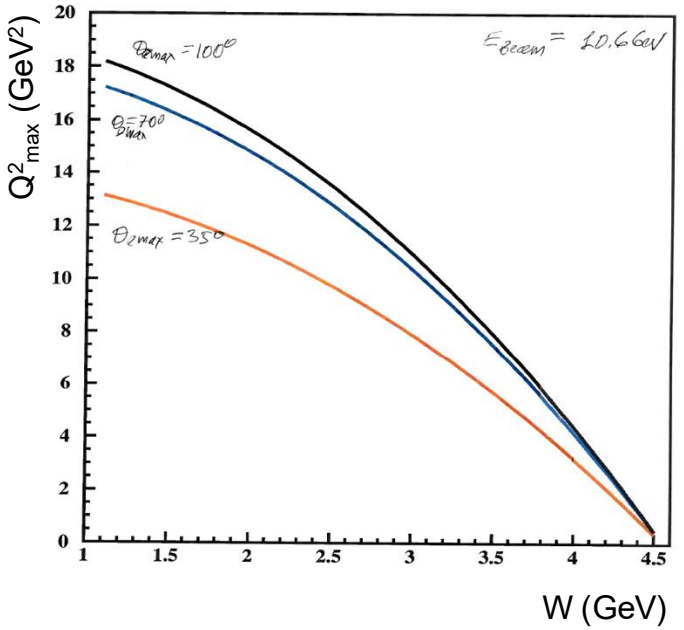
At $\mathcal{L} = 10^{35}$ cm^{-2}s^{-1}, decreasing Q^2-bin size by a factor of two would require beam time of 0.6 year.

After $\mathcal{L}$ increase to 2×10^{35} cm^{-2}s^{-1}, the $\pi^+\pi^-p$ cross sections can be measured up to $Q^2 = 12$ GeV^2 in (Q^2,W) bins, with sufficient statistics for extraction of $\gamma_v pN^*$ electrocoupling exceeding those collected in the current measurements with CLAS12 with finer binning over Q^2.

Other existing and planned facilities will be unable to explore exclusive meson electroproduction in the nucleon-resonance region at Q^2 up to 12 GeV^2, owing to the demanding requirements for high luminosity over a large detector acceptance.

Looking Towards CEBAF-2037 Era

- An increase of maximum lab polar angle for detected scattered electrons up 70° opens a new opportunity to explore the Q^2 evolution of the $\gamma_v pN^*$ electrocouplings for $Q^2<16$ GeV^2.
- A unique opportunity to explore in-hadron sensitivity to the emergence of N* structure across the range of distances where ~75% of hadron mass is generated *addressing challenging problem in Standard Model on the nature of dominant part of the visible hadron mass in the Universe*.



Beam time estimates to collect statistics sufficient for the extraction of the $\gamma_v pN^*$ electrocouplings for $Q^2<16$ GeV^2 for bin sizes $\Delta Q^2 = 0.5$ GeV^2 and $\Delta W = 0.05$ GeV:

0.5 year for $\mathcal{L} = 2\times10^{35}$ cm^{-2}s^{-1}

- Other existing and planned facilities will be unable to explore exclusive meson electroproduction in the nucleon-resonance region at Q^2 up to 16 GeV^2, owing to the demanding requirements for high luminosity over a large detector acceptance.

Back Up

Conclusions and Outlook

- A good description of the $N(938)1/2^+$, $N(1440)1/2^+$, $\Delta(1232)3/2^+$, $\Delta(1600)3/2^+$, $N(1520)3/2^-$, and $\Delta(1700)3/2^-$ electrocouplings for $Q^2<5$ GeV^2 achieved within CSM with the same dressed quark mass function inferred from the QCD Lagrangian offers sound evidence for insight into the momentum dependence of the dressed quark mass, but in a range of distances where <30% of hadron mass is generated.

- An increase in luminosity by a factor of 2 (with unchanged beam energy and maximum polar scattering angle for detected electrons), would enable CLAS12 to access the electrocouplings of all prominent N* states in the unexplored Q^2 range of 5–12 GeV^2, allowing us to cover range of distances where up to 60% of hadron mass is generated.

- As a prospect for CEBAF2037 and beyond, increasing the maximum laboratory scattering angle for detected electrons to 70° may enable the extension of $\gamma_v pN^*$ electrocoupling measurements to Q^2 up to 17 GeV^2. This would offer the only foreseen opportunity to map the dressed-quark mass function and investigate the transition from pQCD to sQCD dynamics at the distances where the largest fraction of N/N* masses (~75%) is generated. *These studies would address one of the most challenging open questions in the Standard Model: the origin of ~94%–98% of the visible mass of hadrons in the Universe.*