Shedding Light on Emergence of Hadron Mass from the Studies of Nucleon Resonance Electroexcitation with CLAS@6 GeV

Composition of the Proton Mass (PDG20):

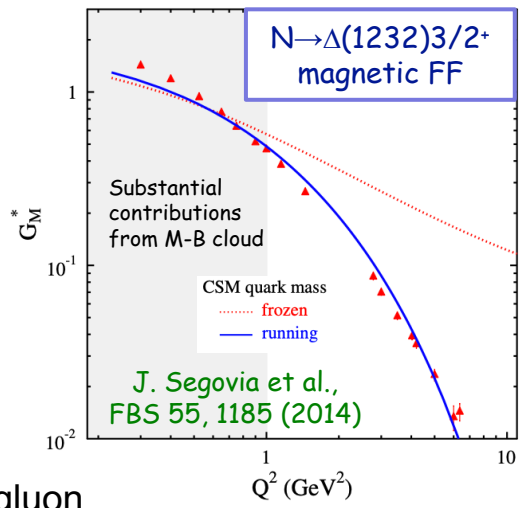
M_p=938.2720813±0.0000058 MeV

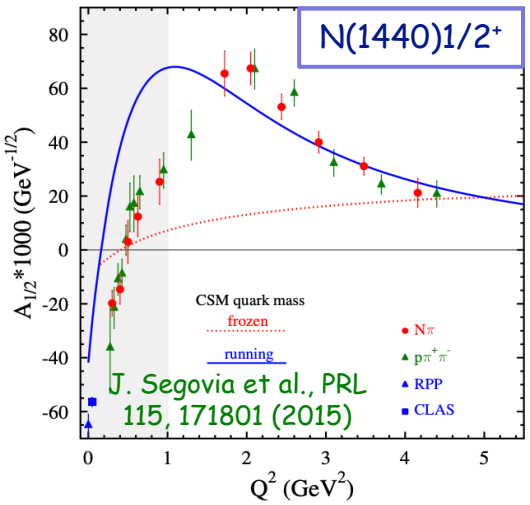
Sum of Higgs masses of current quarks inside proton

$2.16+2.16+4.67=8.99^{+1.45}_{-0.65}$ MeV

The strong interaction in the non-perturbative (sQCD) regime underlies the emergence of >98% of hadron mass

CLAS results vs. CSM expectations





- Solution of QCD equations of motion for quark/gluon fields within Continuum Schwinger method (CSM) reveals dressed quarks/gluons in the sQCD regime with momentum-dependent masses (slide #2) - confirmed by LQCD studies (O. Olivera et al., PRD 99, 094506 (2019))
- Ground/excited states of the nucleon emerge from QCD as bound systems of three dressed quarks with the dominant contribution (> 98%) from their running masses.

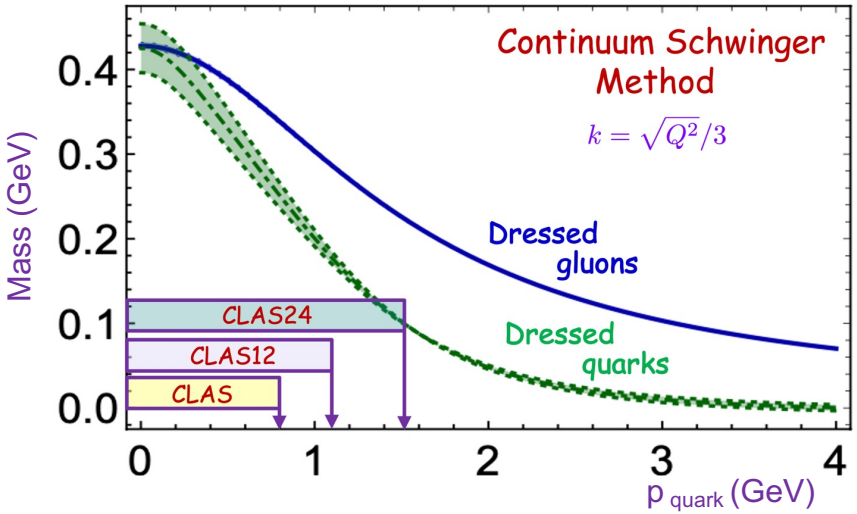
They are the most fundamental 3-body systems in Nature. If we don't understand how they emerge from QCD, then we don't understand Nature.

- Momentum dependence of dressed quark masses can be mapped out from N* electrocouplings (V.I. Mokeev and D.S. Carman, FBS 63, 59 (2022))
- A successful description of the pion and nucleon elastic FFs, and the electrocouplings of nucleon resonances of different structure (Δ(1232)3/2⁺, N(1440)1/2⁺, and Δ(1600)3/2⁺) has been achieved *with the same dressed quark/gluon mass functions*

Compelling evidence for insight into momentum dependence of dressed quark mass at p_{quark} < 0.8 GeV

Unique Opportunities for Understanding Emergence of Hadron Mass and N* Structure 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)



Increasing knowledge on running dressed quark mass from the results on $\gamma_v pN^*$ electrocouplings

	Q^2-range of electrocouplings	Quark momentum range p	Fraction of dressed quark mass at $p<p_{max}$
CLAS	< 5 GeV^2	< 0.7 GeV	15-20%
CLAS12	< 10 GeV^2	< 1.1 GeV	40-50%
CEBAF@ 20+ GeV	< 20 GeV^2	< 1.5 GeV	> 80%

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

$\gamma_v pN^*$ electrocouplings can be determined to $Q^2 \sim 20$ GeV^2 for $\mathcal{L} \sim 3 - 5 \times 10^{35}$ cm^{-2}s^{-1}

- Increasing 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 N* electroexcitation within the range of Q^2 where the dominant portion of hadron mass is expected to be generated.
- Experimental confirmation of CSM predictions of $\gamma_v pN^*$ electrocouplings of most prominent N* states of different structure will provide sound evidence for understanding 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.