

“Two Pion Electroproduction at Large Virtualities.”



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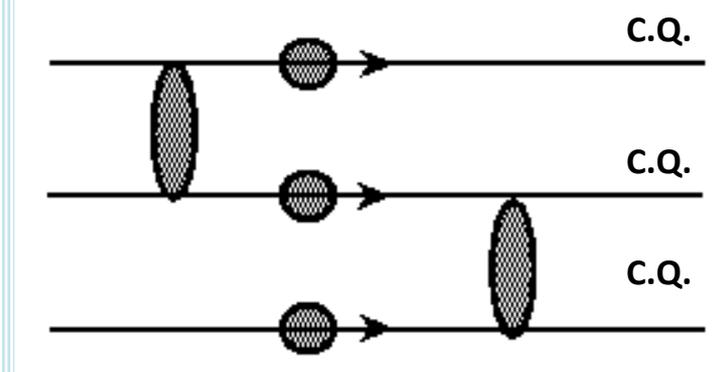
Moscow, October 5-8, 2015

XIV International Seminar on

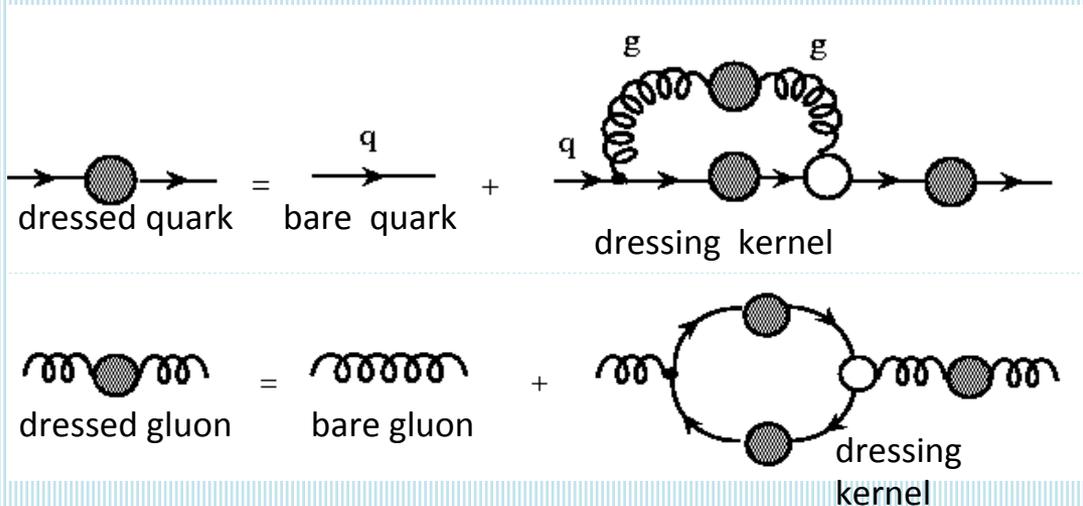
Electromagnetic Interactions of Nuclei

Effective Degrees of Freedom in the Ground and Excited Nucleon State Structure

Phenomenological studies of N^* spectrum supported by recent LQCD results strongly suggest that ground and excited nucleon states consist of three constituent quarks (C.Q.) coupled by non-perturbative interaction (ovals in the plot).



Emergence of dressed quarks and gluons



•Dressed quarks and gluons acquire dynamical structure and momentum dependent mass in the regime of large a_s , which is relevant for the N^* formation.

•Their structure and interaction are beyond the scope of pQCD.

Two conceptually different approaches for description of nucleon/ N^* structure from first QCD principles:

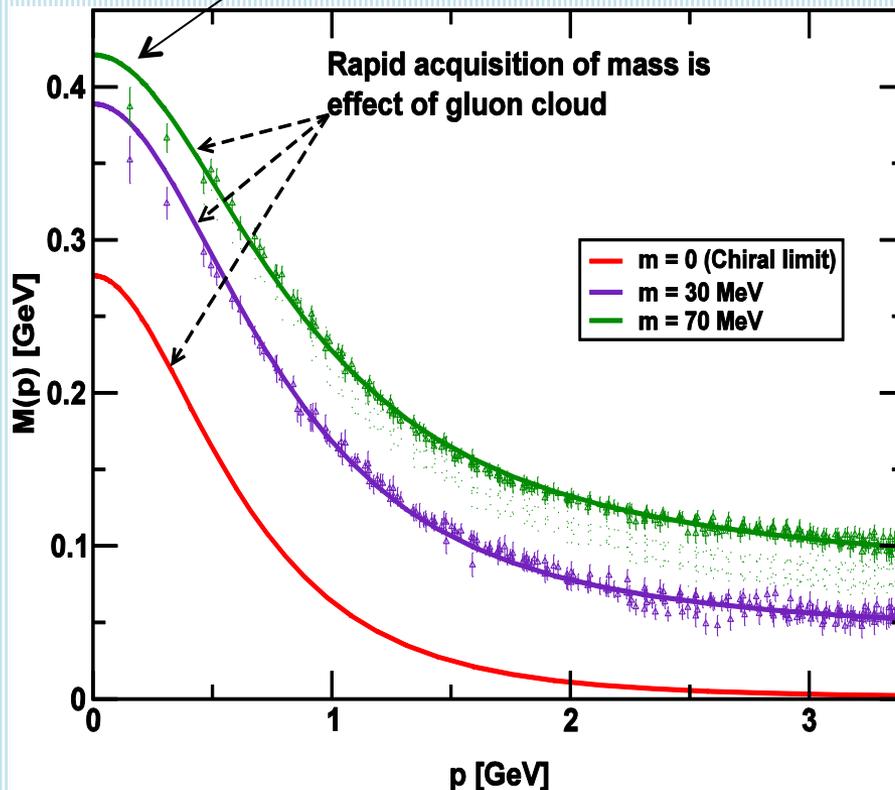
- Lattice QCD (LQCD)
- Dyson-Schwinger Equation of QCD (DSEQCD)

•J.J.Dudek, R.G.Edwards, Hybrid Baryons in QCD, PRD85, 054016 (2012).

•C.D.Roberts, Strong QCD and Dyson-Schwinger Equations, arXiv:1203.5341[nucl-th].

Dressed Quark Evolution from pQCD to Confinement Regimes

quark/gluon confinement



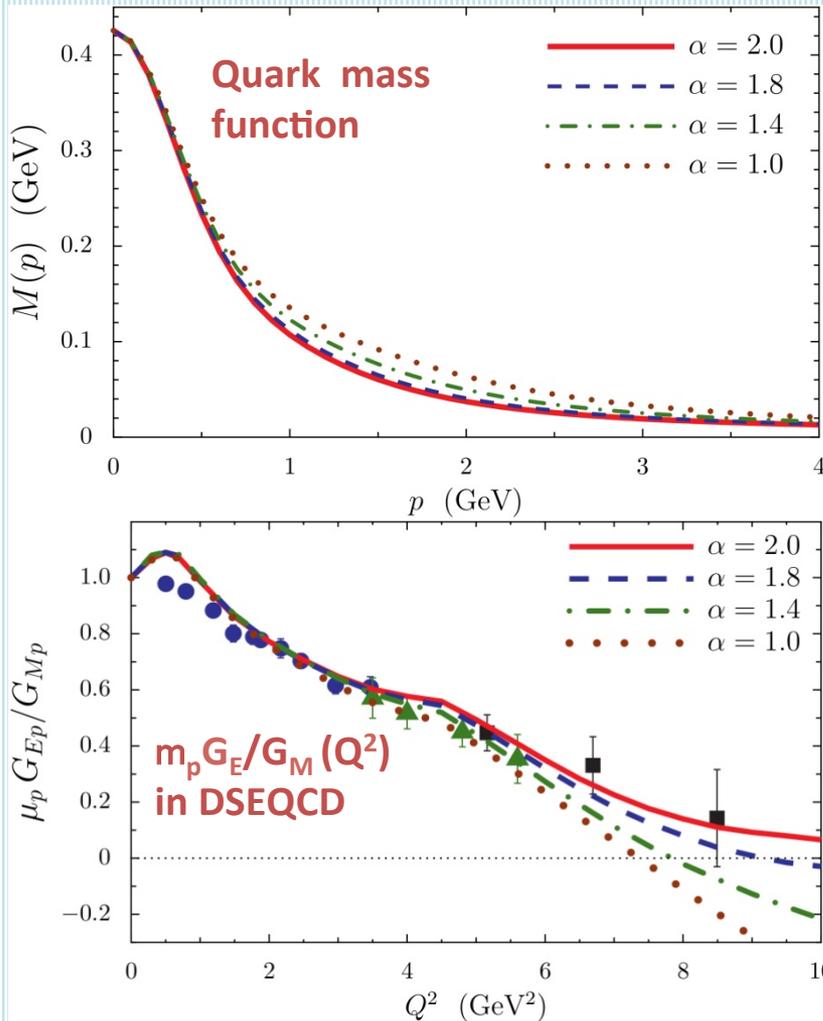
Consistent results from two different based on QCD approaches:

- LQCD - P.O.Bowman, et al., PRD **71**, 054505 (2005) (points with error bars).
- DSEQCD - C.D.Roberts, Prog. Part. Nucl. Phys. **61**, 50 (2008) (lines).

• more than 98% of dressed quark (N/N^*) masses as well as their dynamical structure are generated non-perturbatively through dynamical chiral symmetry breaking (DCSB). The Higgs mechanism accounts for less than 2% of the nucleon & N^* mass.

• the momentum dependence of the dressed quark mass reflects the transition from quark/gluon confinement to asymptotic freedom.

Mapping out Quark Mass Function

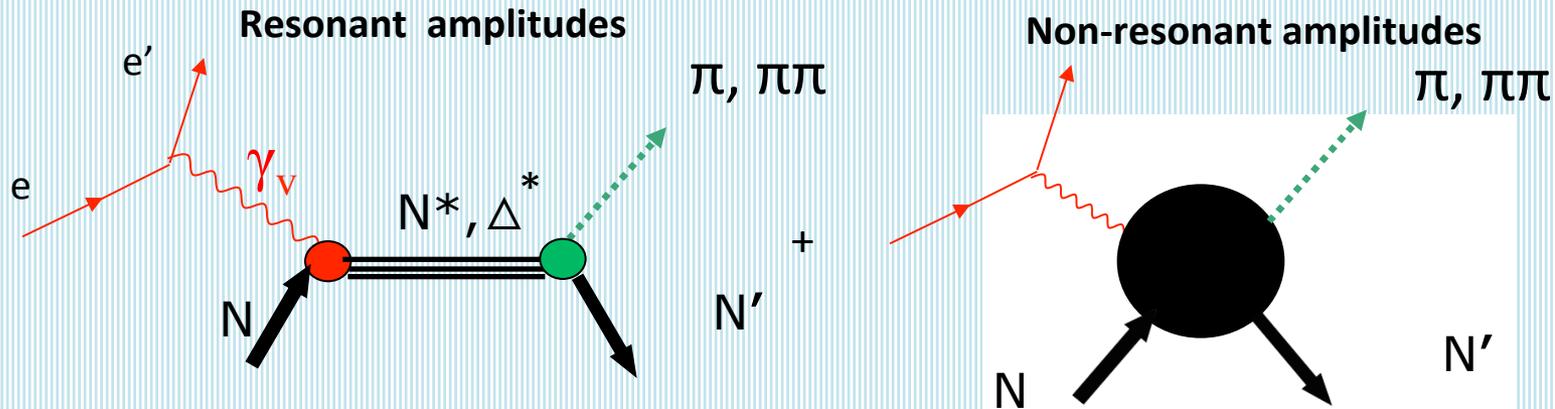


I.C.Cloët, C.D.Roberts, A.W.Thomas,
Phys. Rev. Lett. 111, 101803 (2013).

- elastic form factors are sensitive to momentum dependence of quark mass function.
- mass function should be the same for dressed quarks in the ground and excited nucleon states.
- consistent results on dressed quark mass function determined from the data on elastic form factors and transition $g_V NN^*$ electrocouplings are critical for reliable extraction of this quantity.
- results on transition $g_V NN^*$ electrocouplings offer an access to dynamics of quark-gluon vertex dressing beyond simplified rainbow-ladder truncation.

Studies of $g_V NN^*$ electrocouplings (transition $N \rightarrow N^*$ form factors) represents the central direction in the exploration of strong interaction in non-perturbative regime.

Extraction of $g_{\nu NN^*}$ electrocouplings from the data on exclusive meson electroproduction off protons



- $A_{1/2}(Q^2)$, $A_{3/2}(Q^2)$, $S_{1/2}(Q^2)$
or
- $F_1(Q^2)$, $F_2(Q^2)$, $F_3(Q^2)$
or
- $G_M(Q^2)$, $G_E(Q^2)$, $G_C(Q^2)$

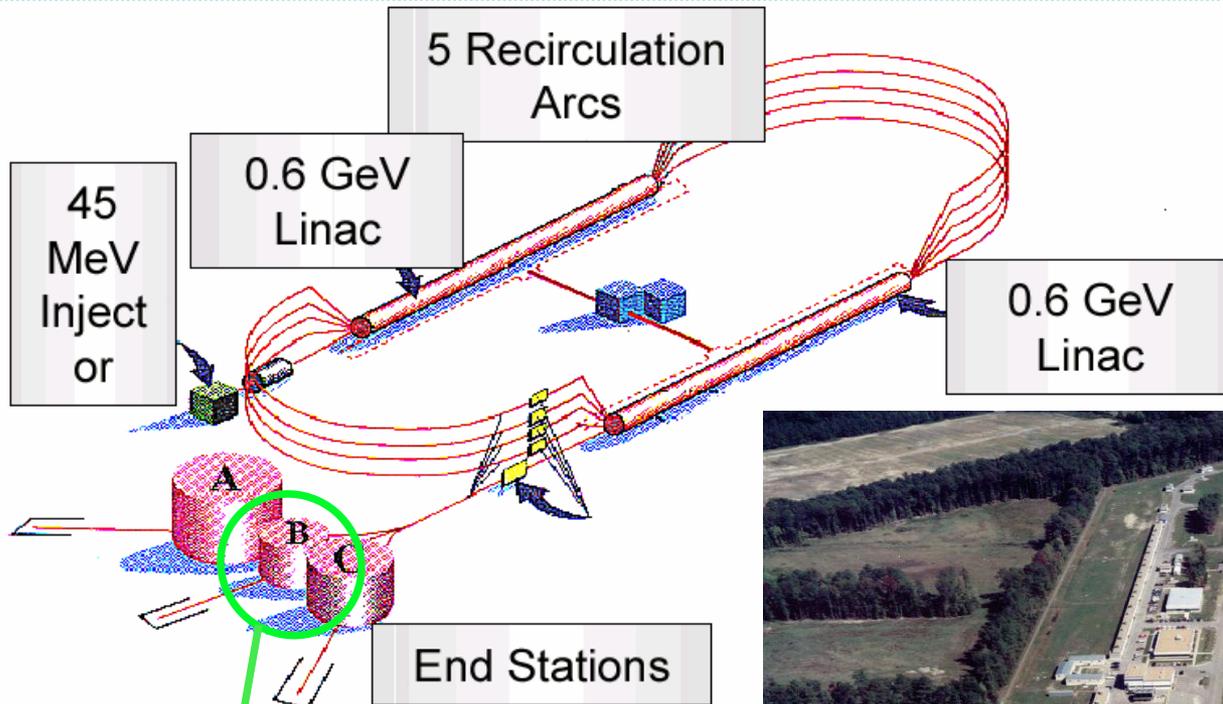
N^* 's photo-/electrocouplings $g_{\nu NN^*}$ are defined at $W=M_{N^*}$ through the N^* electromagnetic decay width :

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

See details in:
I.G.Aznauryan and
V.D.Burkert, *Progr.
Part. Nucl. Phys.* 67, 1
(2012).

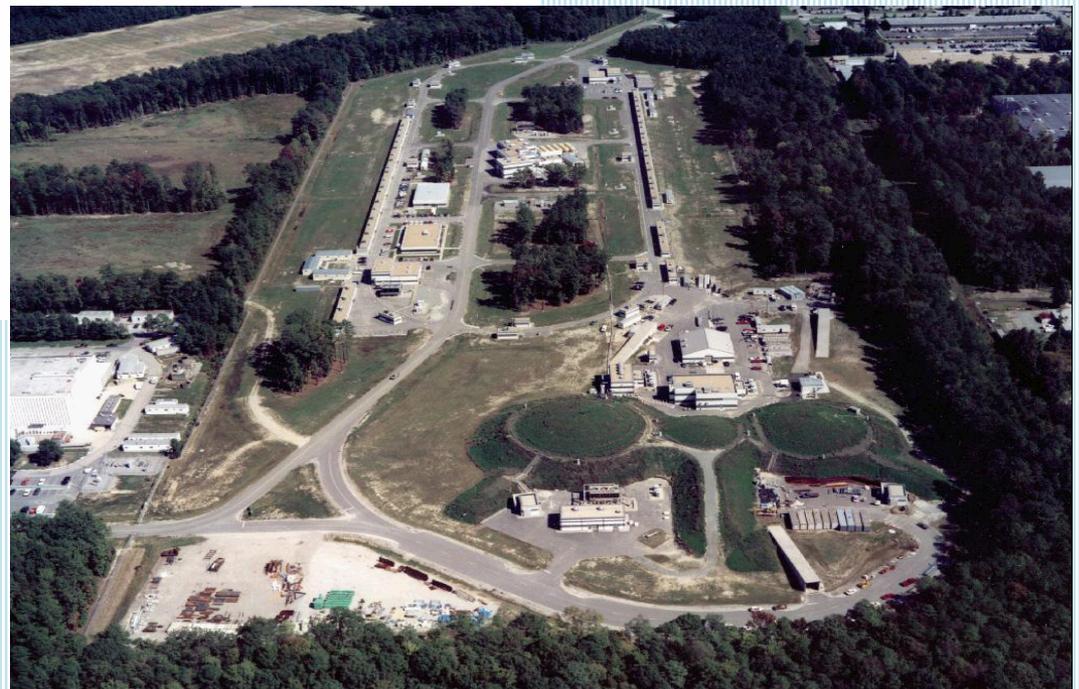
- Consistent results on $g_{\nu NN^*}$ electrocouplings from different meson electroproduction channels and different analysis approaches demonstrate reliable extraction of N^* parameters.
- For electrocouplings extracted from one pion channels, please see paper by Ki Jun Park and I.G.Aznauryan et al., CLAS Coll., *Phys Rev.* C80, 055203 (2009).

Jefferson Lab – CEBAF



E_{\max}	$\sim 6 \text{ GeV}$
I_{\max}	$\sim 200 \text{ mA}$
Duty Factor	$\sim 100\%$
s_E/E	$\sim 2.5 \cdot 10^{-5}$
Beam P	$\sim 80\%$
$E_{g(\text{tagged})}$ GeV	$\sim 0.8 - 5.5$

CLAS



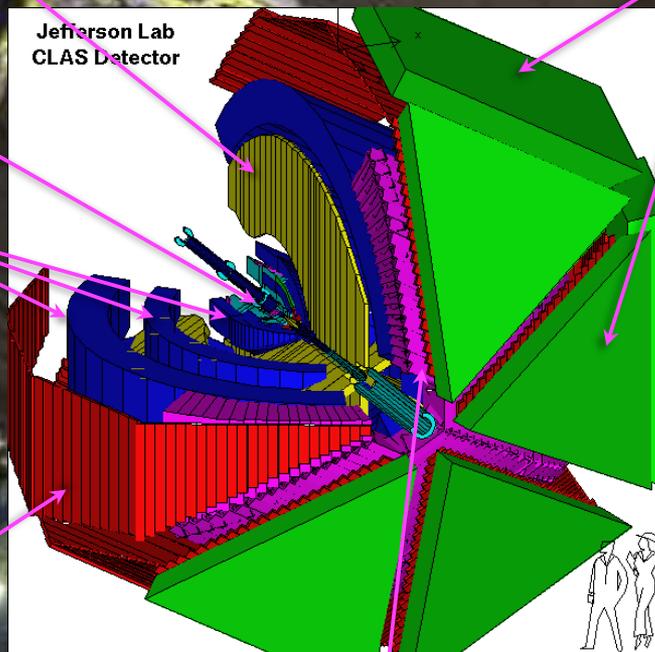
CEBAF Large Acceptance Spectrometer 1997-2012

Torus magnet
6 superconducting coils

Electromagnetic calorimeters
Lead/scintillator, 1296 photomultipliers

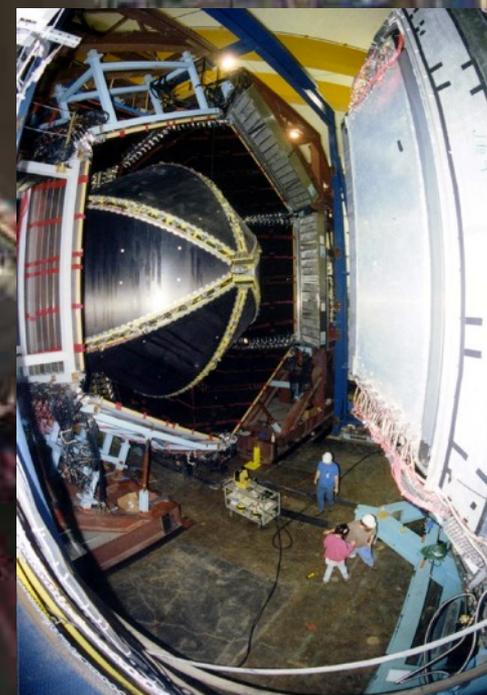
target + start counter

Drift chambers
35,000 cells

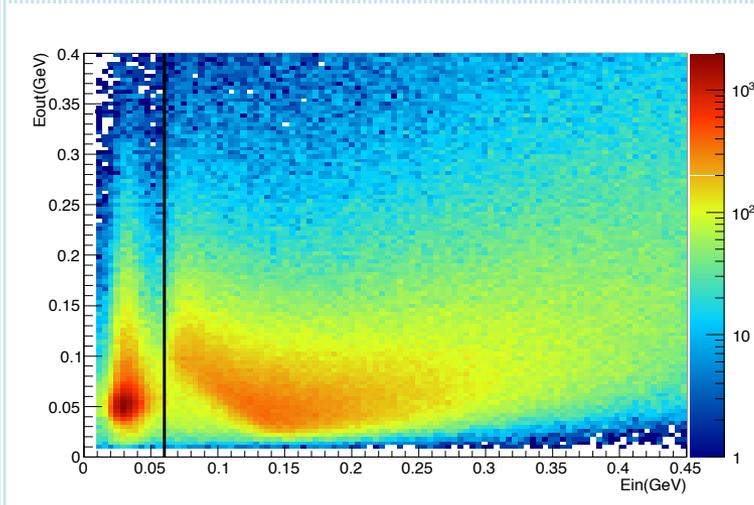


Time-of-flight counters
plastic scintillators, 684 photomultipliers

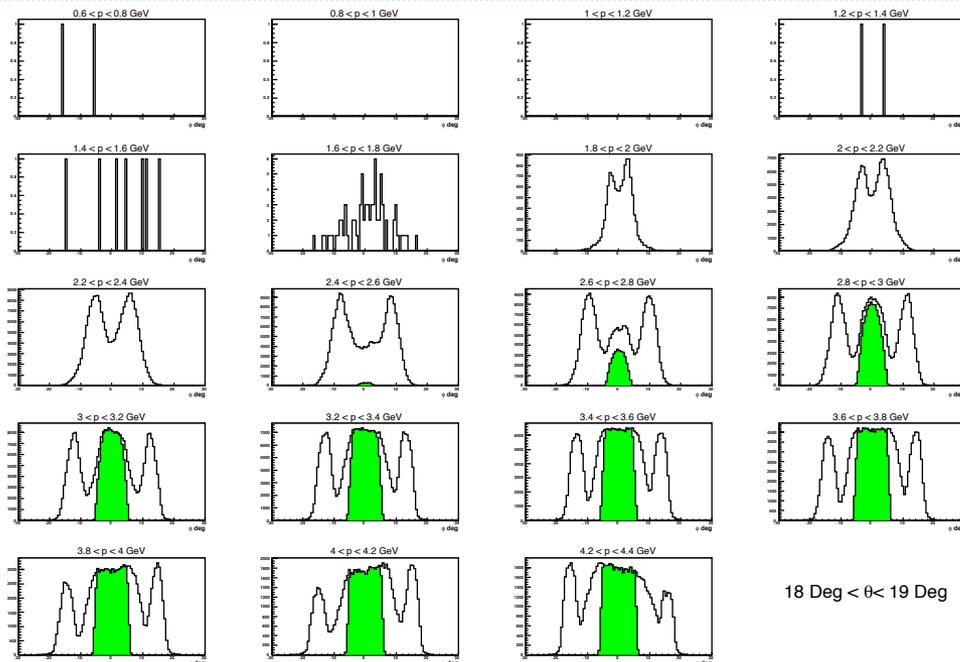
Gas Cherenkov counters
e/ μ separation, 256 PMTs



Electron ID

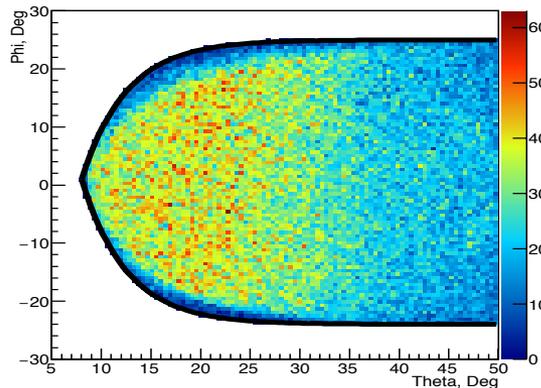
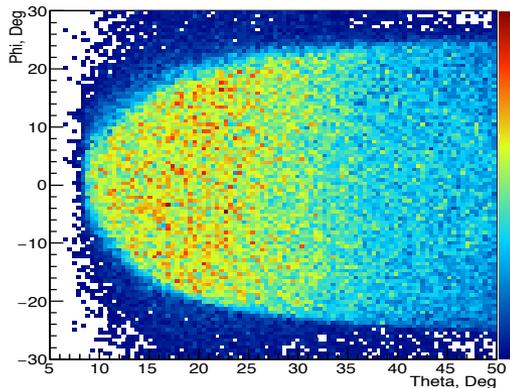
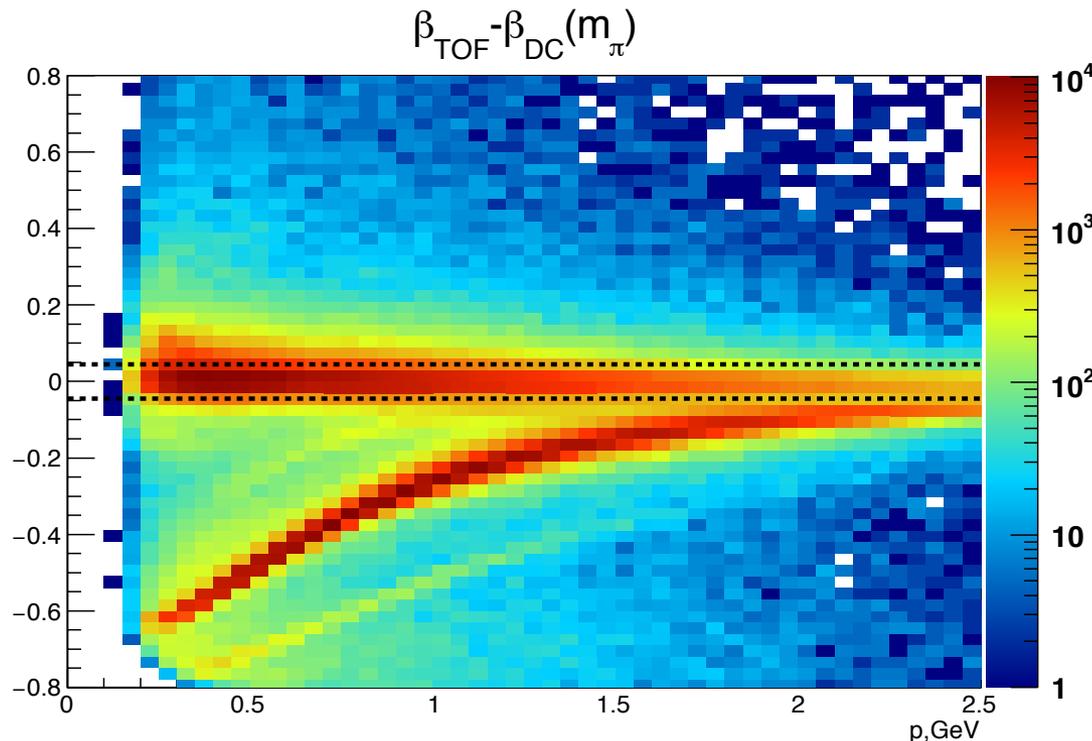


- First track, negative charge + signals in DC, EC, CC
- Status>0
- Calorimeter cuts ($E_{in} > 60$ MeV, $P_e > 700$ MeV, sampling fraction cut, EC fiducial cut)
- Fiducial cuts
- Zvertex corrections, Zvertex cut ($0.8 < Z_v < 8.0$ cm)
- Momentum corrections

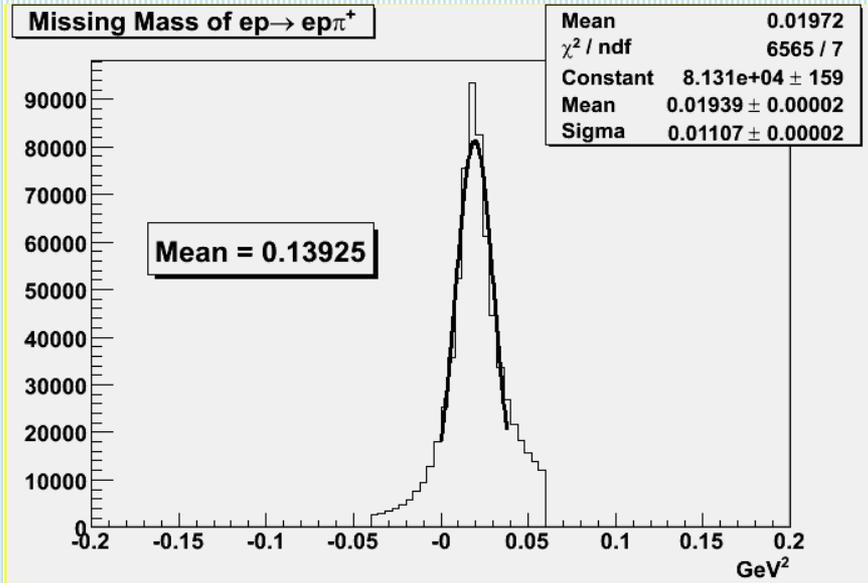


Hadron ID

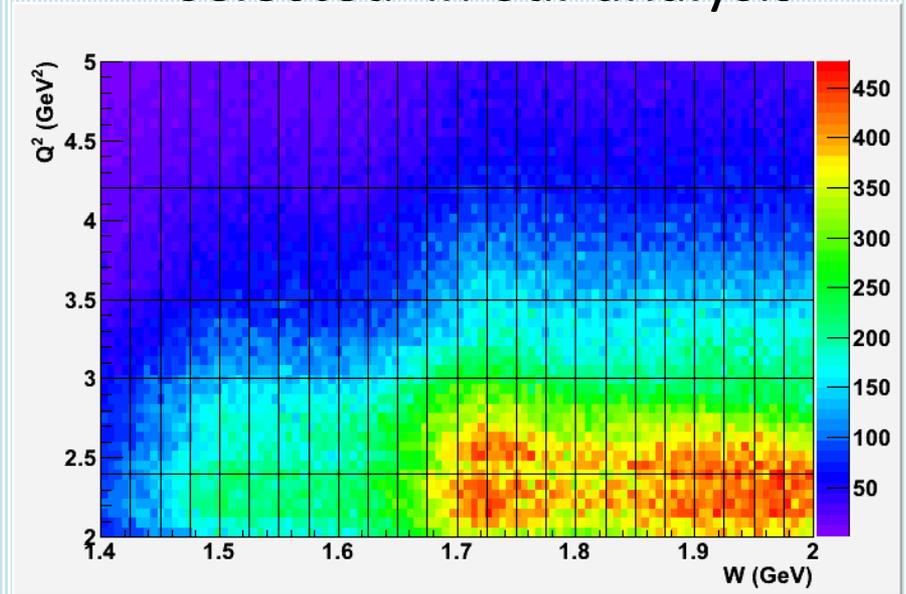
- Beta vs Momentum cuts
- Fiducial cuts
- Momentum corrections for the positive pion
- Energy loss corrections for the proton



Exclusivity cut



W & Q² distribution for $\pi^+ \pi^- p$ events selected in our analysis



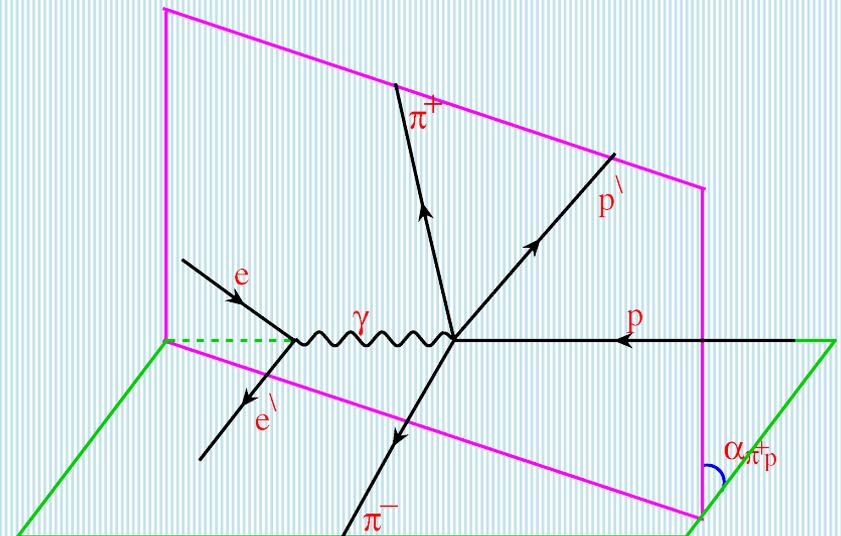
3-body final state kinematics variables

3-body final state kinematics variables:

$M_{\pi\pi}$, $M_{p\pi}$ are invariant masses of the $\pi^+\pi^-$ and $p\pi^+$ systems respectively;

$d\Omega = d(\cos\theta)d\phi$ is solid angle for emitted π^- ;

$\alpha_{p\pi^+}$ is the angle between two planes on the plot.



Cross-section extraction

$$\frac{d^7\sigma}{dWdQ^2d\tau} = \frac{1}{L} \cdot \frac{\Delta N}{\text{eff} \cdot \Delta W \Delta Q^2 \Delta \tau}$$

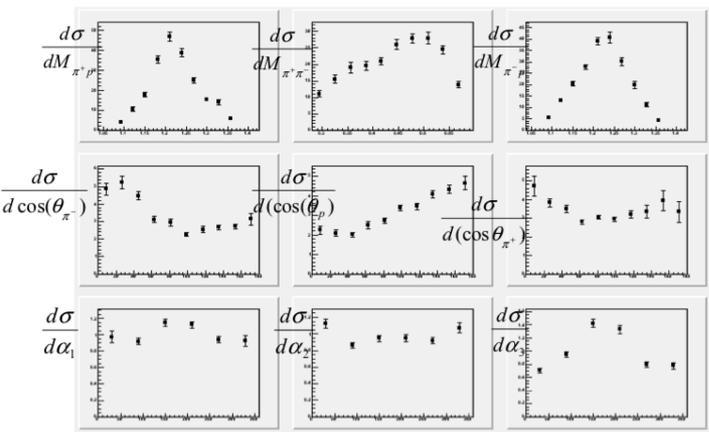
7-fold differential cross-section

$$d\tau = dM_{\pi^+\pi^-} dM_{\pi^+p} d\cos(\theta_{\pi^-}) d\varphi_{\pi^-} d\alpha_{\pi^+p}$$

L – luminosity, ΔN – number of events inside multidimensional cell, eff-efficiency determined from monte-carlo simulation. Then we obtain virtual photon cross-section

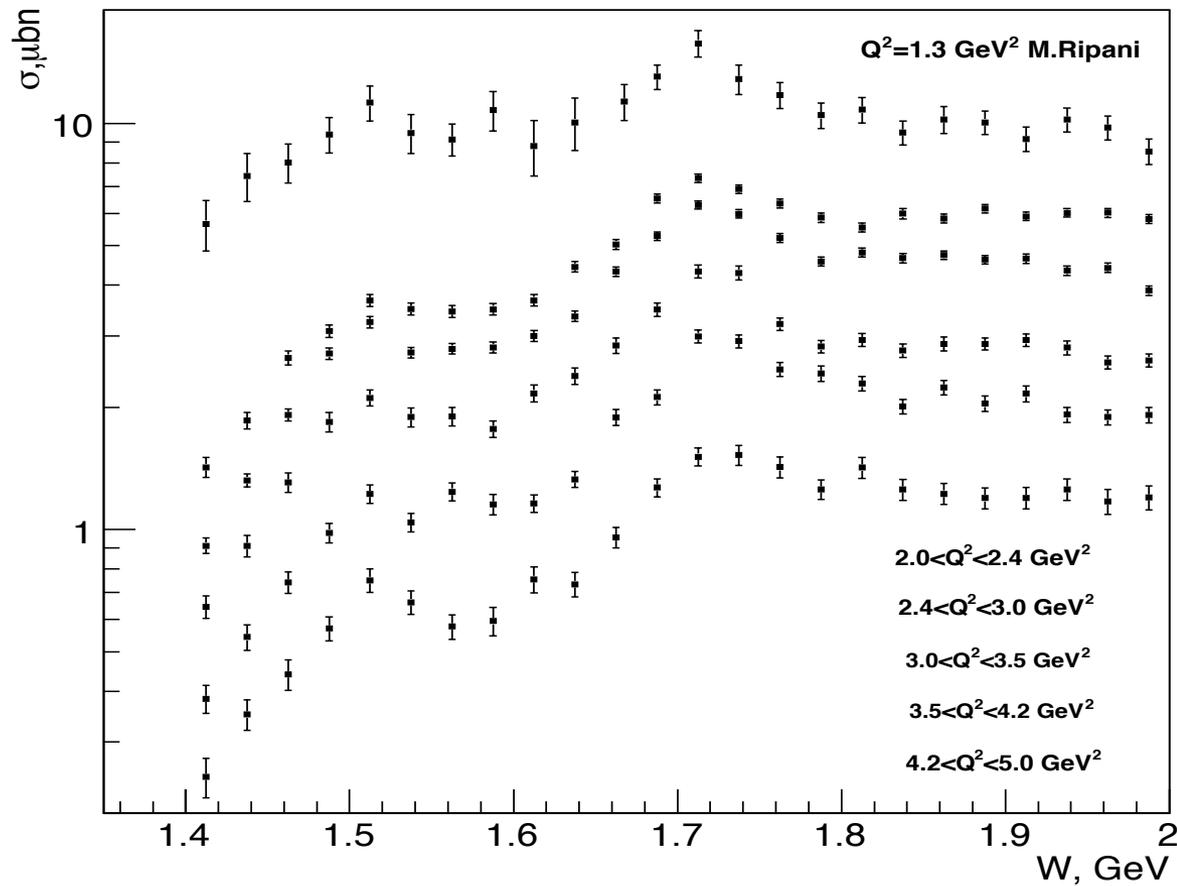
$$\frac{d^5\sigma}{d\tau} = \frac{1}{\Gamma_v} \frac{d^7\sigma}{dWdQ^2d\tau}$$

$2.0 < Q^2 < 2.4 \text{ GeV}^2$ $1.5 < W < 1.525 \text{ GeV}$



Example of nine 1-fold differential cross-sections

Cross-sections obtained by integrating in 5 variables



D13(1520)
S11(1535)

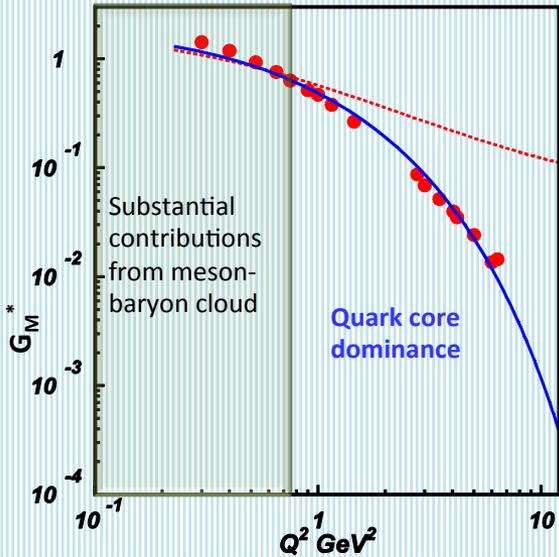
D33(1700), P13(1720)
 $3/2^+(1720)$, F15(1685)

Access to the Dressed Quark Mass Function from the Data on the Transition $N \rightarrow N^*$ Form Factors

D(1232)3/2⁺

Jones-Scadron convention

J. Segovia et al., Few Body Syst. 55,1185 (2014).

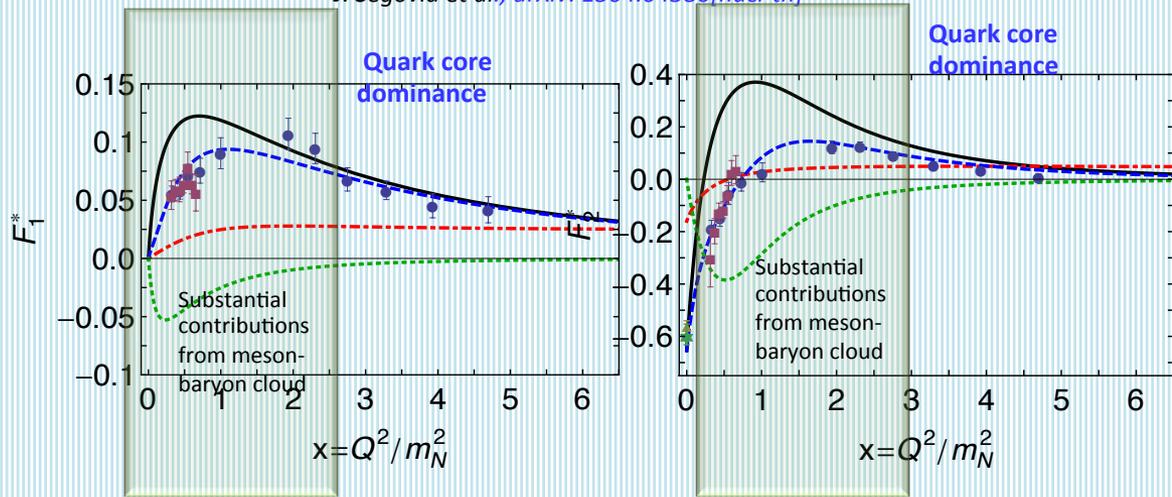


N(1440)1/2⁺

Dirac F_1^* and Pauli F_2^*

$N \rightarrow N(1440)1/2^+$ transition form factors

J. Segovia et al., arXiv: 1504.04386[nucl-th]



The quark core contributions to transition form factors computed in a common DSEQCD framework starting from the QCD Lagrangian:

- Contact qq interaction, frozen constituent quark mass.
- Realistic qq interaction, running quark mass.
- Realistic qq interaction, running quark mass,
- Meson-Baryon cloud contribution

Good data description at $Q^2 > 3.0 \text{ GeV}^2$ achieved with the same dressed quark mass function for the ground and excited nucleon states of distinctively different structure provides the strong evidence for:

- the relevance of dressed quark predicted by DSEQCD
- promising prospect to map out dressed quark mass function from combined analyses of the data on nucleon elastic and transition form factors with available and future CLAS12 data at $Q^2 < 12 \text{ GeV}^2$

Conclusions and outlook

- **Nine one-fold differential two-pion electroproduction cross-sections for $1.4 < W < 2.0$ GeV, $2.0 < Q^2 < 5.0$ GeV² were extracted for the first time with CLAS detector in Jefferson Lab.**
- **Analysis of this data in JM model for the first time will allow us to obtain electrocouplings for most excited proton states at $2.0 < Q^2 < 5.0$ GeV². The consistent results extracted from $N\pi$ & $N\pi\pi$ channels will strongly indicate a reliable electrocoupling measurement. For the first time information on electrocouplings of high lying nucleon excitations with masses above 1.6 GeV will be available at photon virtuality from 2.0 to 5.0 GeV².**
- **Successful description of elastic and transition form factors to different low-lying resonances achieved at $Q^2 > 2.5$ GeV² within the framework of DSEQCD demonstrated promising opportunity to probe dressed quark mass function from the data on elastic and transition form factors getting an access to the essence of non-perturbative strong interaction and its emergence from QCD.**