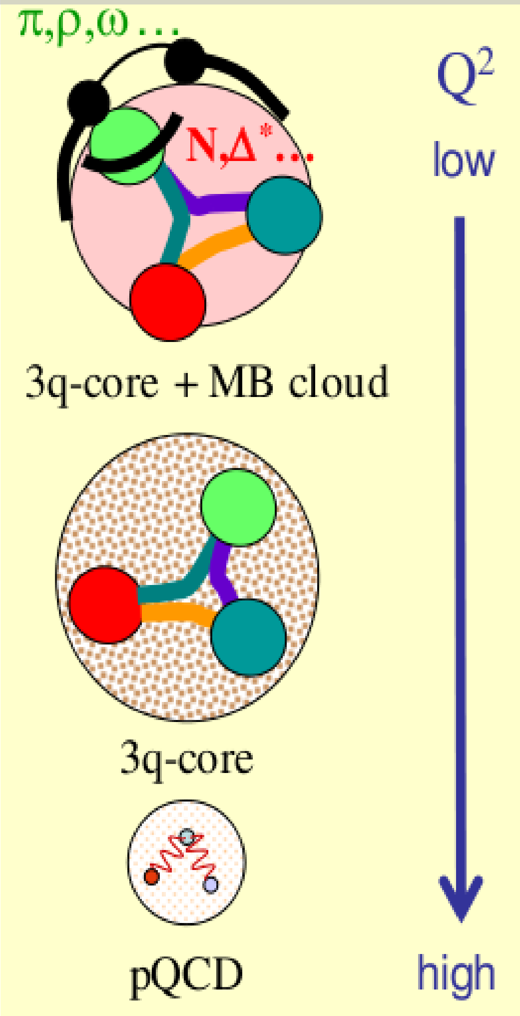
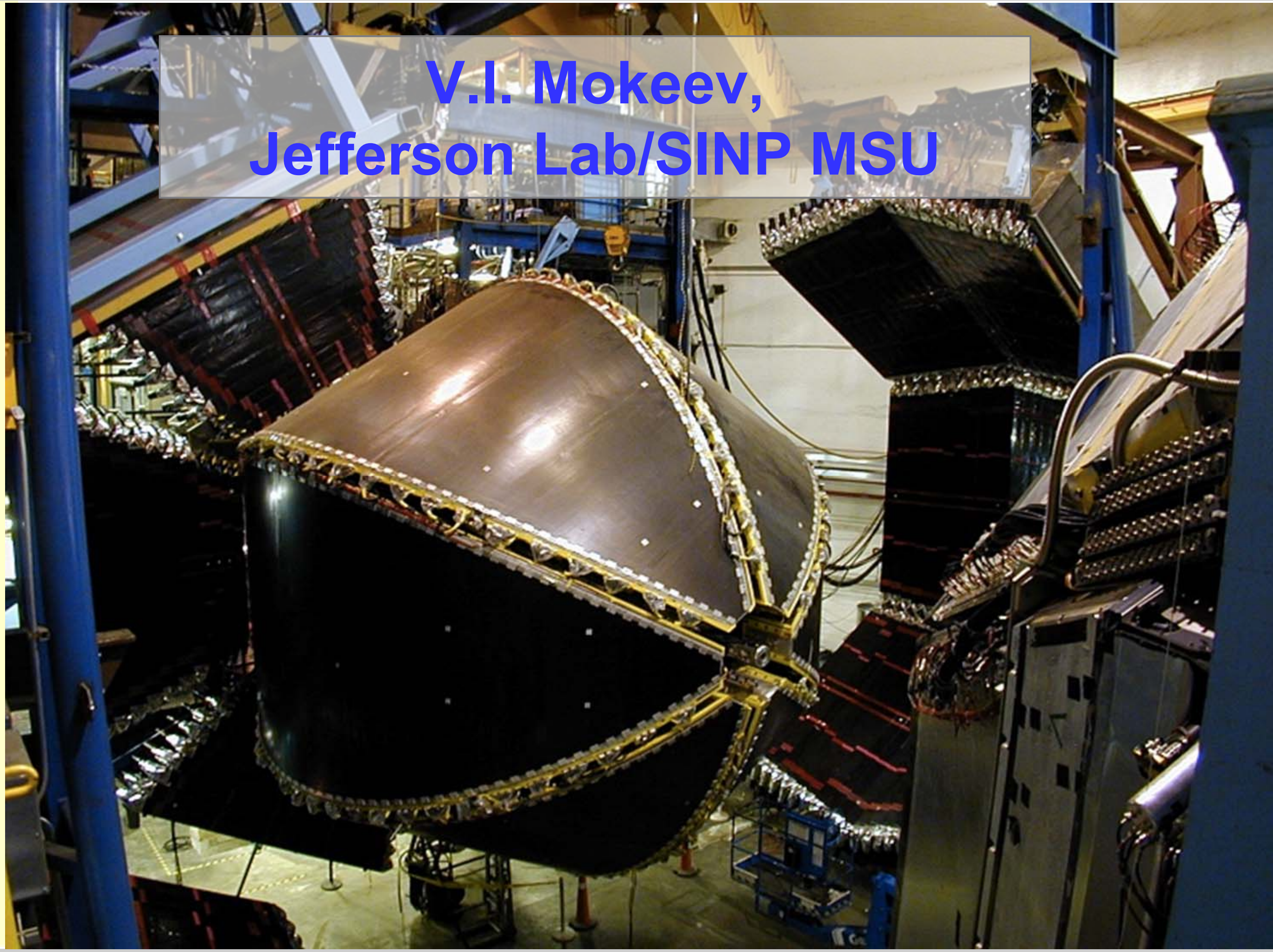
Studies of N* Structure in Collaboration between SINP at MSU and Hall-B at JLAB

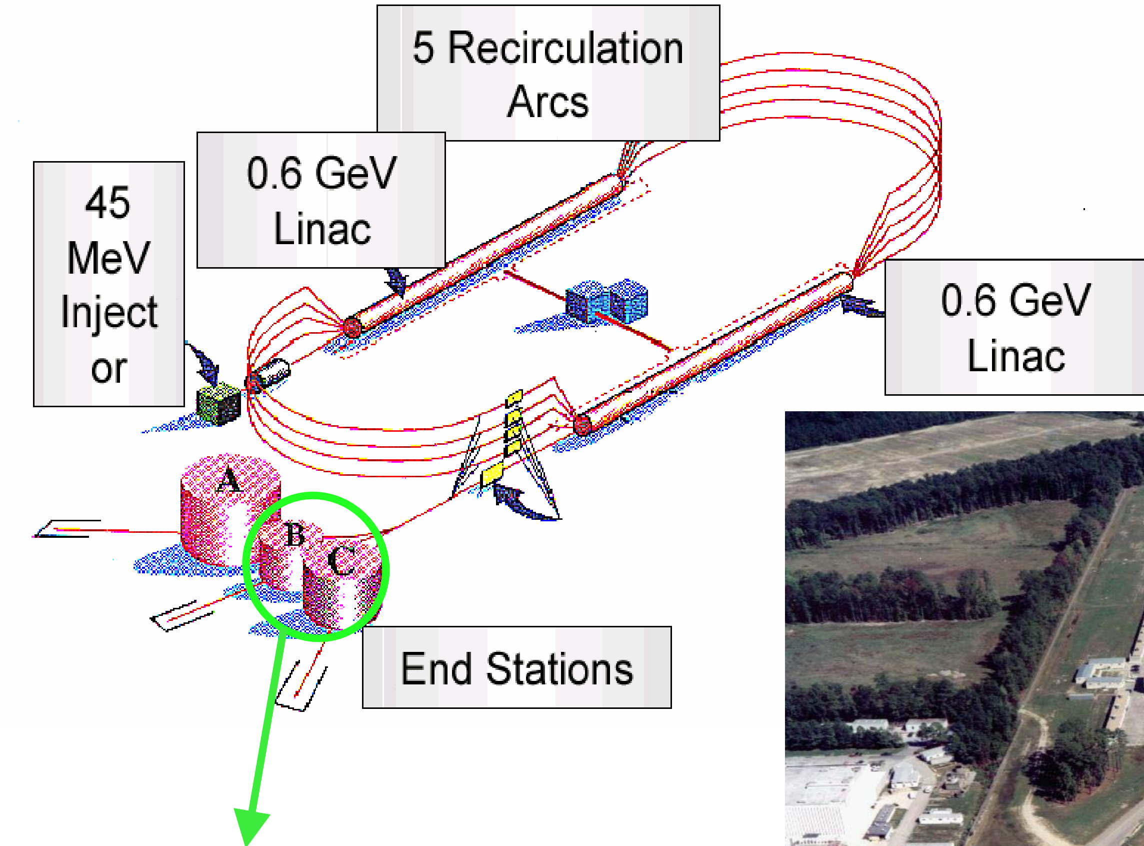




V.I. Mokeev,
Jefferson Lab/SINP MSU

Seminar on Nuclear Physics in SINP at MSU

Ускоритель электронов непрерывного действия в Jefferson Lab – CEBAF



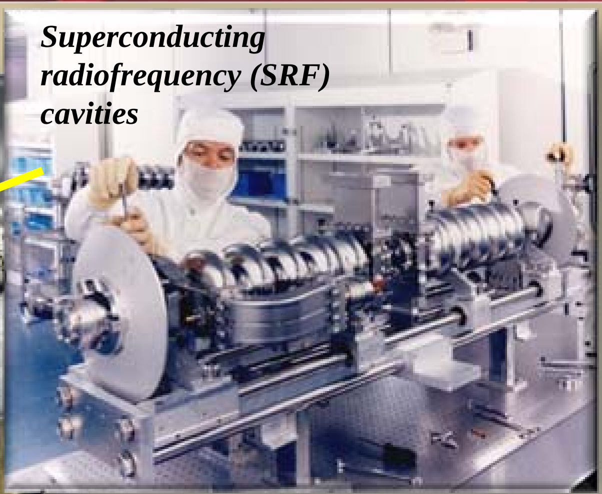
CLAS

E_{max}	~ 6 GeV
I_{max}	~ 200 μA
Duty Factor	~ 100%
σ_E/E	~ 2.5 10^{-5}
Beam P	~ 80%
E_g(tagged)	~ 0.8- 5.5 GeV

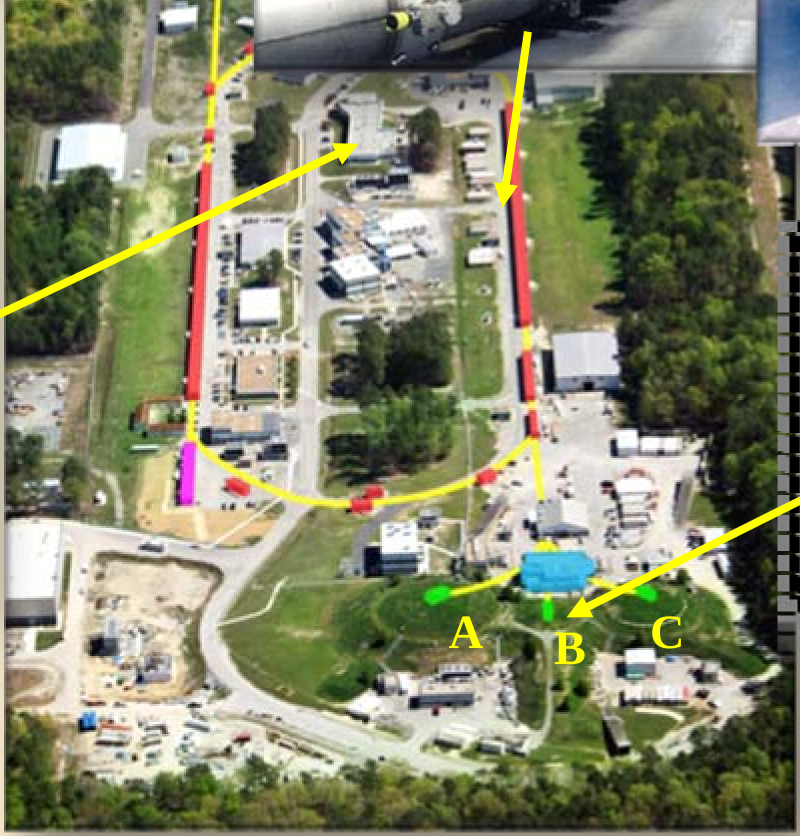
Current Jefferson Lab Accelerator Complex

Hall D (new construction)

Cryomodules in the accelerator tunnel



Superconducting radiofrequency (SRF) cavities



Free Electron Laser (FEL)

CEBAF Large Acceptance Spectrometer (CLAS) in Hall B

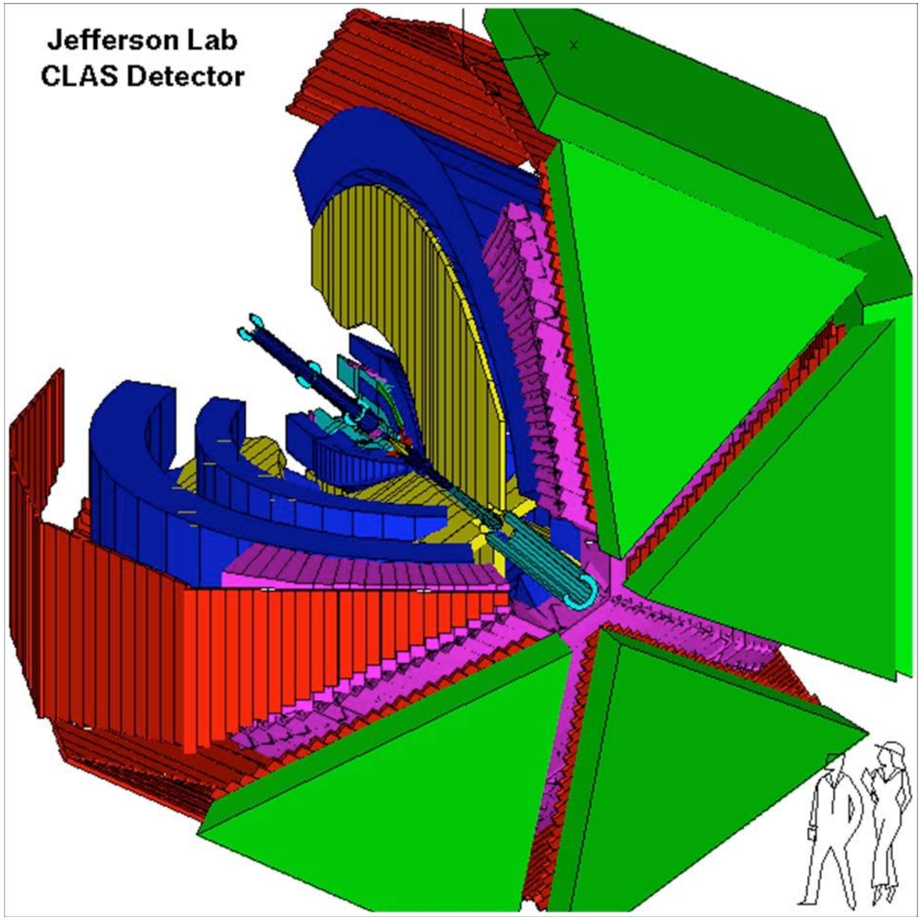
CEBAF Large Acceptance Spectrometer

Torus magnet
6 superconducting coils

Liquid D_2 (H_2)target +
γ start counter; e minitorus

Drift chambers
argon/CO_2 gas, 35,000 cells

Time-of-flight counters
plastic scintillators,
684 PMTs



Large angle calorimeters
Lead/scintillator, 512 PMTs

Gas Cherenkov counters
e/π separation, 216 PMTs

Electromagnetic calorimeters
Lead/scintillator, 1296 PMTs

The unique combination of the CEBAF continuous electron beam and the CLAS detector makes Hall-B@JLAB the only facility operational worldwide, that is capable of measuring unpolarized cross sections and polarization asymmetries of most exclusive meson electroproduction channels with substantial contributions at W<3.0 GeV and Q^2<5.0 GeV^2.

The review of the results in N* physics with CLAS:

- I.Aznauryan, V.Burkert, T-S.H.Lee, and V.Mokeev, J.Phys. Conf.Ser. **299,** 012008 (2011).

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

The 6 GeV era came to successful close in May 12'after fifteen years of running many productive world-class experiments. We are poised to continue our very successful experimental program with CLAS12.

Major Directions in the Studies of N*-Spectrum and Structure with CLAS

The experimental program on the studies of N* spectrum/structure in exclusive meson photo-/electroproduction with CLAS seeks to determine:

- $\gamma_v NN^*$ electrocouplings at photon virtualities up to 5.0 GeV^2 for most of the excited proton states through analyzing major meson electroproduction channels
- extend knowledge on N*-spectrum and on resonance hadronic decays from the data for photo- and electroproduction reactions with multiple mesons in the final state

A unique source of information on different manifestations of the non-perturbative strong interaction in generating different excited nucleon states as relativistic bound systems of quarks and gluons.

The leading contribution from OEPVAYa group to the N* studies in exclusive $\pi^+\pi^-p$ photo-/electroproduction.

Review papers:

1. I.G. Aznauryan and V.D. Burkert, Progr. Part. Nucl. Phys. 67, 1 (2012).
2. I.G. Aznauryan et al., Int. J. Mod. Phys. E22, 133015 (2013).
3. I.C. Cloët and C.D. Roberts, Prog. Part. Nucl. Phys. 77, 1 (2014).

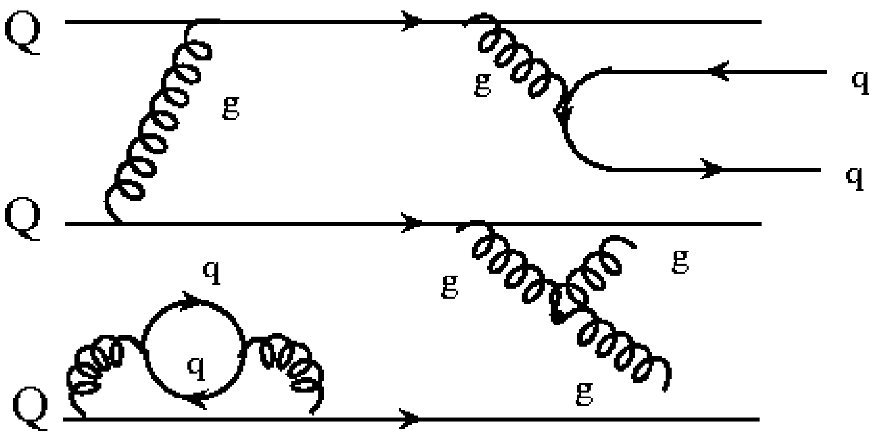
The Ground and Excited Nucleon State Structure as a Key part in Exploration of Hadron Matter

•Nucleons and pions are the first stable composite systems of quarks and gluons generated after the Big Bang by strong interaction.

•The ground and excited nucleon states open up the unique prospects to explore quark-gluon confinement and hadron mass generation.

•Building blocks of atomic nuclei, important part in exploration of the nuclear medium.

The structure of the nucleon ground state from the studies of nucleon elastic form factors and inelastic parton structure functions:



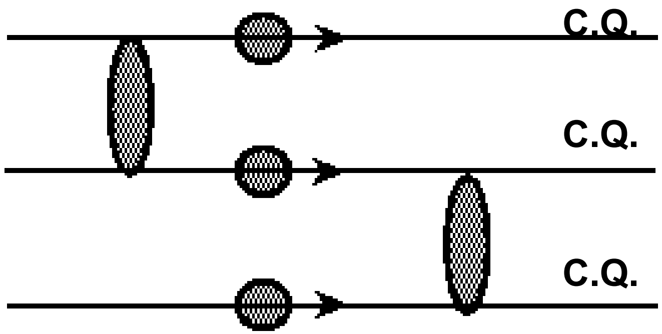
Three valence current quarks (Q) embedded in the sea of gluons (g) and $q\bar{q}$-pairs

Particular features of nucleon structure:

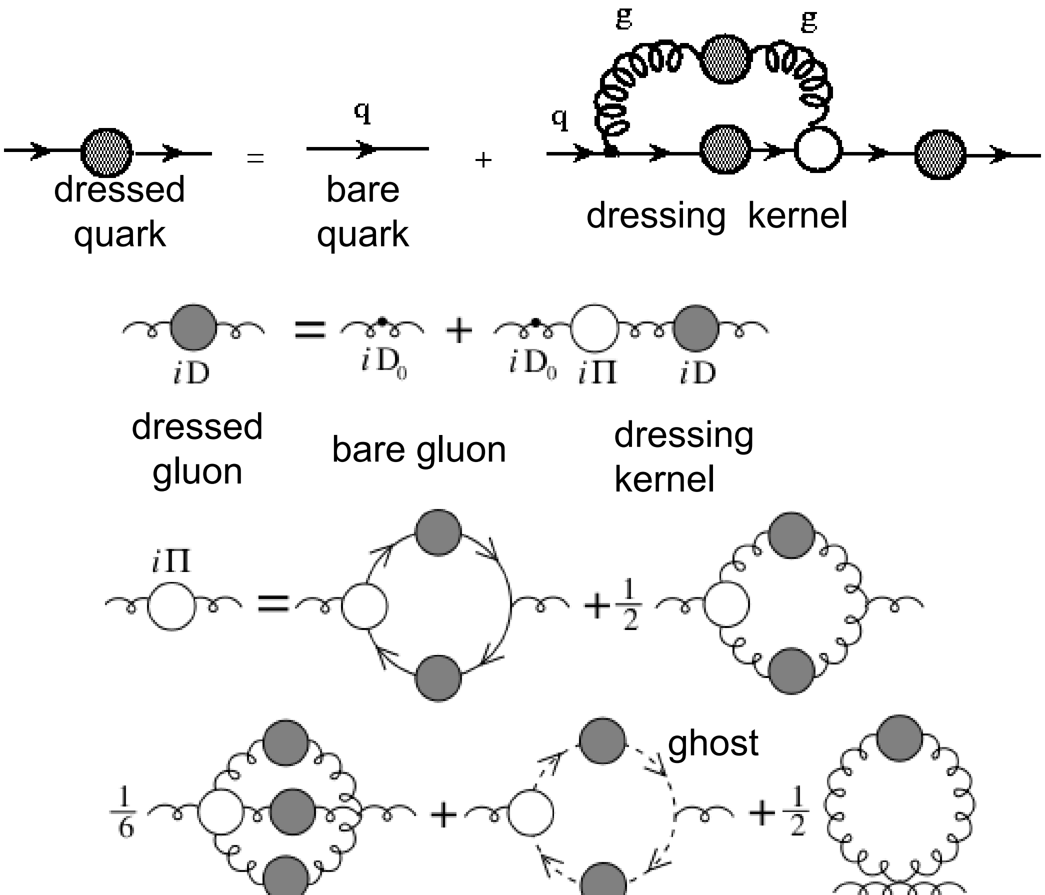
•infinite amount of contributing current quarks and gauge gluons;
• leading role of quark/gluon creation and annihilation;
•all constituents are substantially off-shell;
•important role of relativistic effects.

Full power of Poincare covariant Quantum Field Theory is needed for the nucleon structure exploration

Studies of N* spectrum/structure suggest that ground and excited nucleon states consist of three dressed (constituent) quarks (C.Q.) coupled by non-perturbative strong interaction (ovals in the plot).

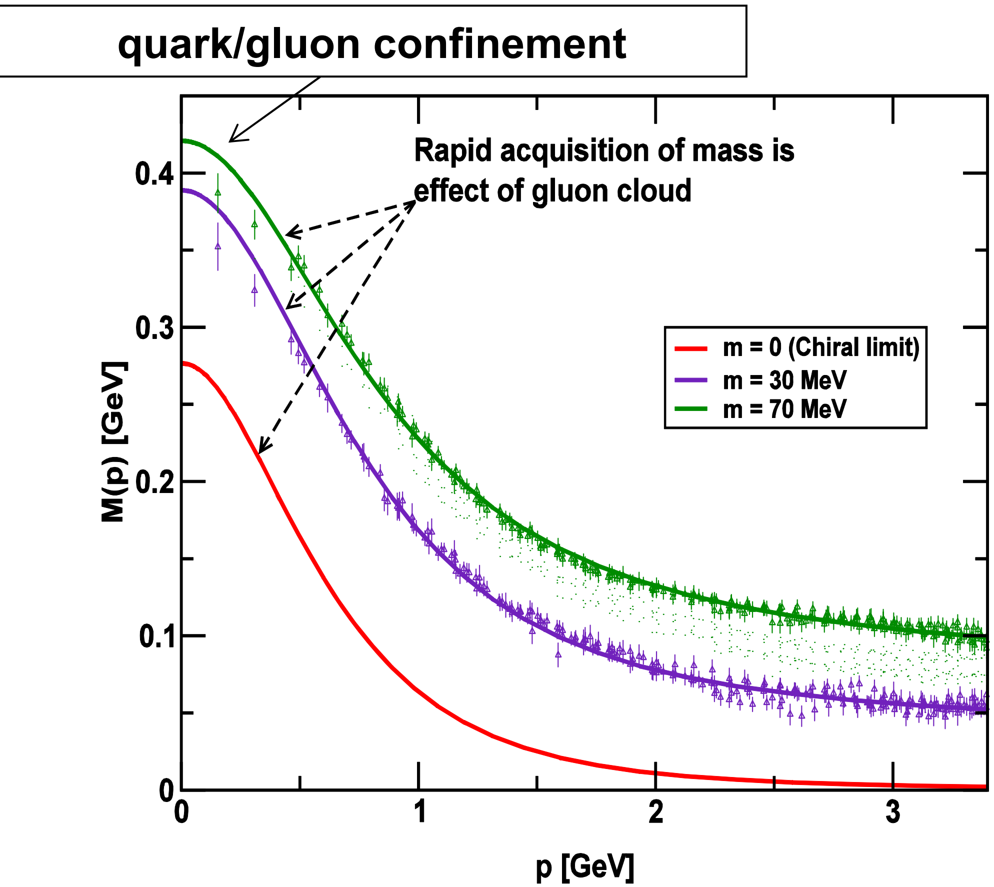


Emergence of dressed quarks and gluons



In the regime of large α_s that is relevant for N* formation, dressed quarks and gluons are substantially different with respect to the bare quarks and gauge gluons. They acquire dynamical structure and momentum-dependent mass.

Dressed Quark Evolution from pQCD to Confinement Regimes



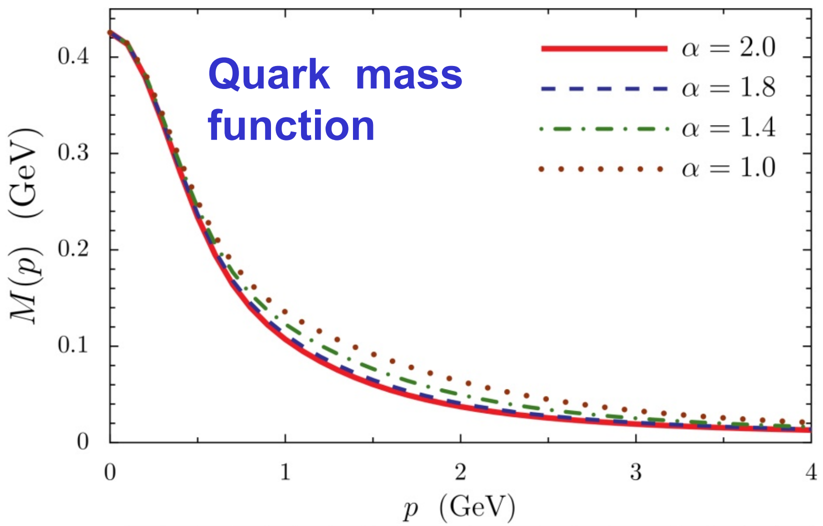
Consistent results from two different QCD-based approaches:

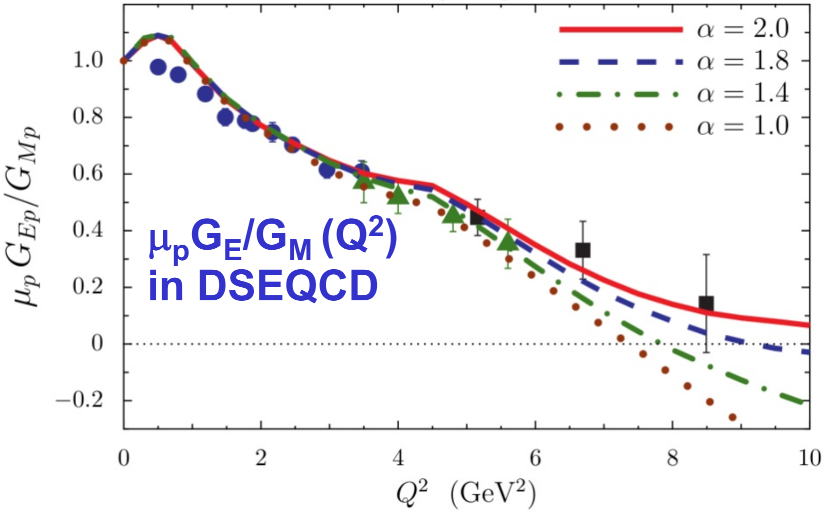
•LQCD - P.O. Bowman, et al., PRD **71**, 054505 (2005) (points with error bars).
•DSEQCD – C.D. Roberts, Prog. Part. Nucl. Phys. **61,** 50 (2008) (lines).

• **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.**

Quark Mass Function from the Studies of N/N* Structure





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 γ_vNN* electrocouplings are critical for reliable extraction of this quantity.**

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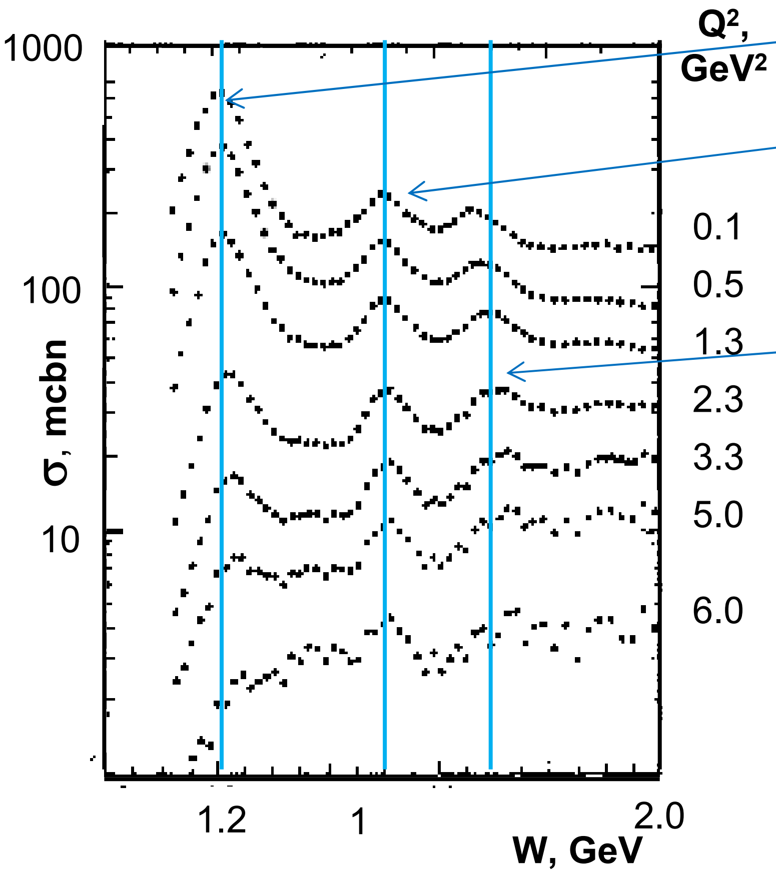
Studies of γ_vNN* electrocouplings (transition N→N* form factors) represent the central direction in the exploration of the strong interaction in the non-perturbative regime.

N*-States in Inclusive Electron Scattering

Total virtual photon cross sections
F. Foster and G.Hughes, Rep. Progr. Phys. 46, 1445 (1983).



The peak content

Δ(1232)3/2+

N(1440)1/2+
N1520)3/2-
N(1535)1/2-
Δ(1620)1/2-

N(1650)1/2-
N(1685)5/2+
Δ(1700)3/2-
N(1710)1/2+
N(1720)3/2+
New CLAS state:
N'(1720)3/2+

What we knew 30 years ago:

- three resonant peaks.
- different Q^2-evolution of these peaks

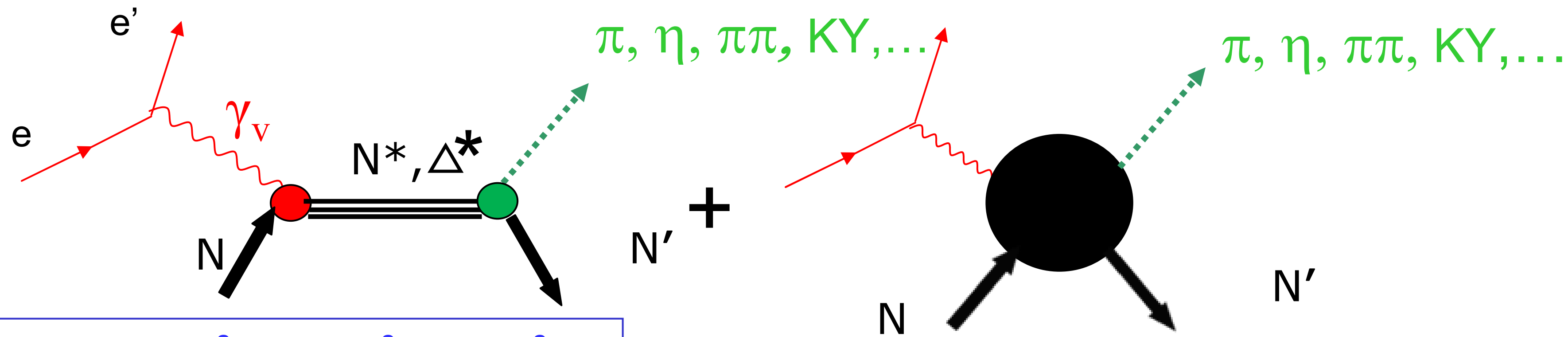
↓

- different structure of different N*-states.

Substantial overlap between different N*-states and sizable non-resonant contributions prevent extraction of N* parameters from inclusive data only. The data on exclusive meson electroproduction are needed for exploration of the N* structure.

Extraction of $\gamma_v NN^*$ Electrocouplings from the Exclusive Meson Electroproduction off Nucleons

Resonant amplitudes **Non-resonant amplitudes**



•Real $A_{1/2}(Q^2)$, $A_{3/2}(Q^2)$, $S_{1/2}(Q^2)$
or
•$G_1(Q^2)$, $G_2(Q^2)$, $G_3(Q^2)$
or
•$G_M(Q^2)$, $G_E(Q^2)$, $G_C(Q^2)$
I.G. Aznauryan and V.D. Burkert, Progr. Part. Nucl. Phys. 67, 1 (2012).

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

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

Γ_γ stands for N* electromagnetic decay widths at the photon point ($Q^2=0$) and $W=M_{N^*}$ on the real energy axis.

- **Consistent results on $\gamma_v NN^*$ electrocouplings from different meson electroproduction channels and different analysis approaches demonstrate reliable extraction of these quantities.**

Summary of the CLAS Data on Exclusive Meson Photo-/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 1.1-1.7 1.6-2.0	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	0.16-0.36 0.4-1.8 3.0-6.0	$d\sigma/d\Omega$ $d\sigma/d\Omega$, A_b,A_t,A_{bt} $d\sigma/d\Omega$
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 thresh-2.6	1.40-3.90 0.70-5.40	$d\sigma/d\Omega$ P’
$\pi^+\pi^- p$	1.3-1.6 1.4-2.1	0.2-0.6 0.5-1.5	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 asym-metries
- P^0 , P’ –recoil and transferred polarization of strange baryon

Almost full coverage of the final hadron phase space in πN, $\pi^+\pi^-$p, ηp, and KY electroproduction.

The data on exclusive electroproduction for all listed final states are available from CLAS and stored in the CLAS Physics Data Base http://clas.sinp.msu.ru/cgi-bin/jlab/db.cgi operated by OEPVAYa:

M. Stepanov, V. Chesnokov

Approaches for Extraction of $\gamma_v NN^*$ Electrocouplings from the CLAS Exclusive Meson Electroproduction Data

- **Analyses of different exclusive electroproduction channels independently:**

➢ **$\pi^+ n$ and $\pi^0 p$ 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 Coll., Phys Rev. C80, 055203 (2009).

I.G. Aznauryan et al., CLAS Coll., Phys. Rev. C91, 045203 (2015).

Reggeized background employing DR & Finite Energy Sum Rules: under development by JPAC

➢ **ηp channel:**

Extension of UIM and DR

I.G. Aznauryan, Phys. Rev. C68, 065204 (2003).

Data fit at W<1.6 GeV, assuming $S_{11}(1535)$ dominance

H. Denizli et al., CLAS Coll., Phys. Rev. C76, 015204 (2007).

➢ **$\pi^+\pi^- p$ channel:**

Data driven JLAB-MSU meson-baryon model (JM) developed in Hall-B/OEPVAYa collaboration

V.I. Mokeev, V.D. Burkert et al., Phys. Rev. C80, 045212 (2009).

V.I. Mokeev et al., CLAS Coll., Phys. Rev. C86, 035203 (2012).

V.I. Mokeev, V.D. Burkert et al., arXiv:1509.05460[nucl-ex].

B_5 Veneziano model for 3-body background: under development by JPAC

Global coupled-channel analyses of the CLAS/world data of $\gamma_{r,v}N$, πN, ηN, $\pi\pi N$, $K\Lambda$, $K\Sigma$ exclusive channels under development by Argonne-Osaka Collaboration:

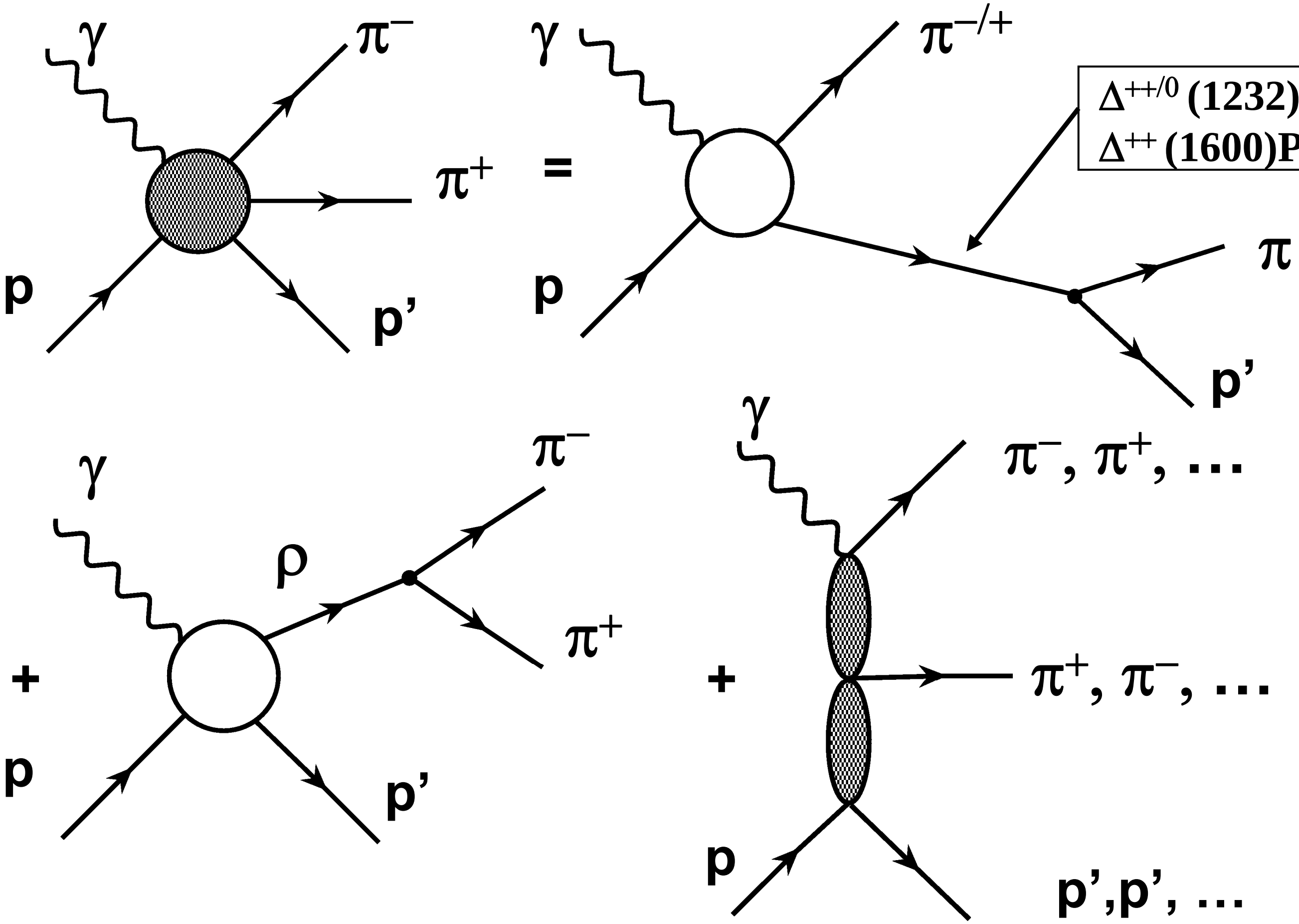
T.-S. H. Lee , AIP Conf. Proc. 1560, 413 (2013).

H. Kamano et al., Phys. Rev. C88, 035209 (2013).

boson.physics.sc.edu/~gote/ect*~15/program.html
Talks at the ECT*2015 Workshop by. T-S.H.Lee, H.Kamano

JM Model Analysis of the $\pi^+\pi^-p$ Electroproduction

Major objectives: extraction of $\gamma_v NN^*$ electrocouplings and $\pi\Delta$, ρp decay widths.



- six meson-baryon channels and direct $\pi^+\pi^-p$ production.
- N* contribute to $\pi\Delta$ and ρp channels only.
- unitarized Breit-Wigner ansatz for resonant amplitudes.

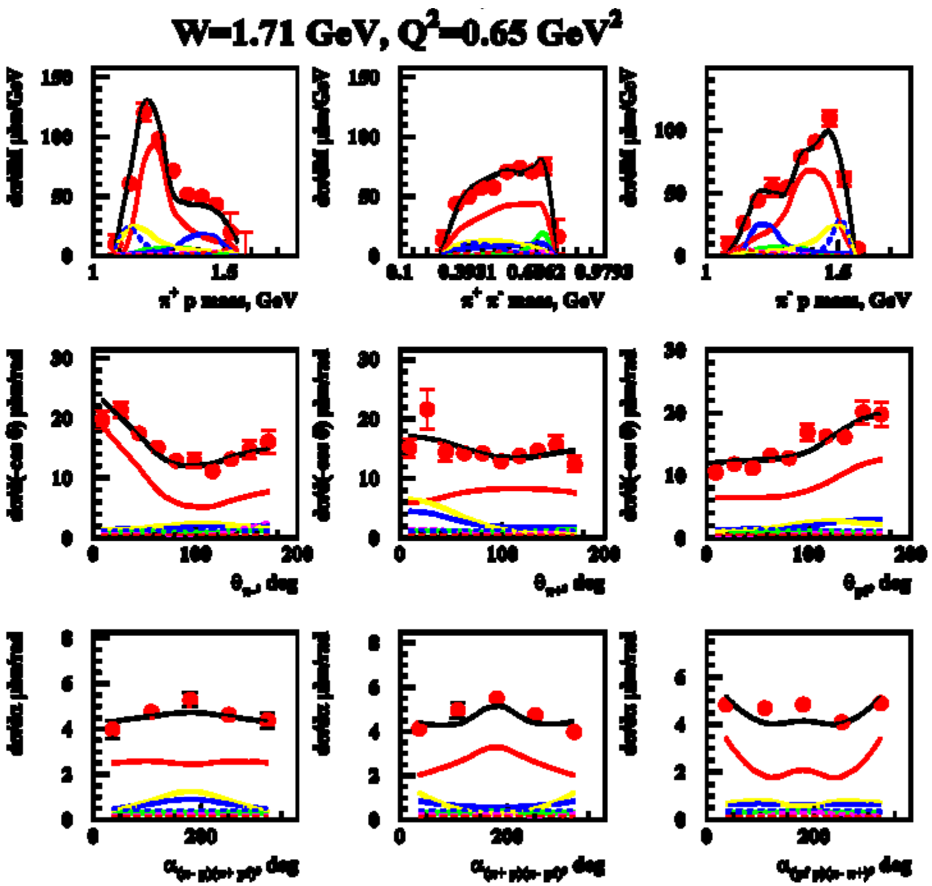
- V.I.Mokeev, V.D. Burkert, et al., (CLAS Collaboration) Phys. Rev. C86, 035203 (2012).
- V.I.Mokeev, V.D. Burkert , et al., Phys. Rev. C80, 045212 (2009).

Only available worldwide approach for extraction of N* parameters from exclusive $\pi^+\pi^-p$ electroproduction

Fits to Differential Cross Sections

$\gamma_v p \to \pi^+ \pi^- p$

M. Ripani, E.N.Golovach et al., PRL 91, 022002 (2003),
1.40<W<2.30 GeV; 0.5<Q^2<1.5 GeV^2

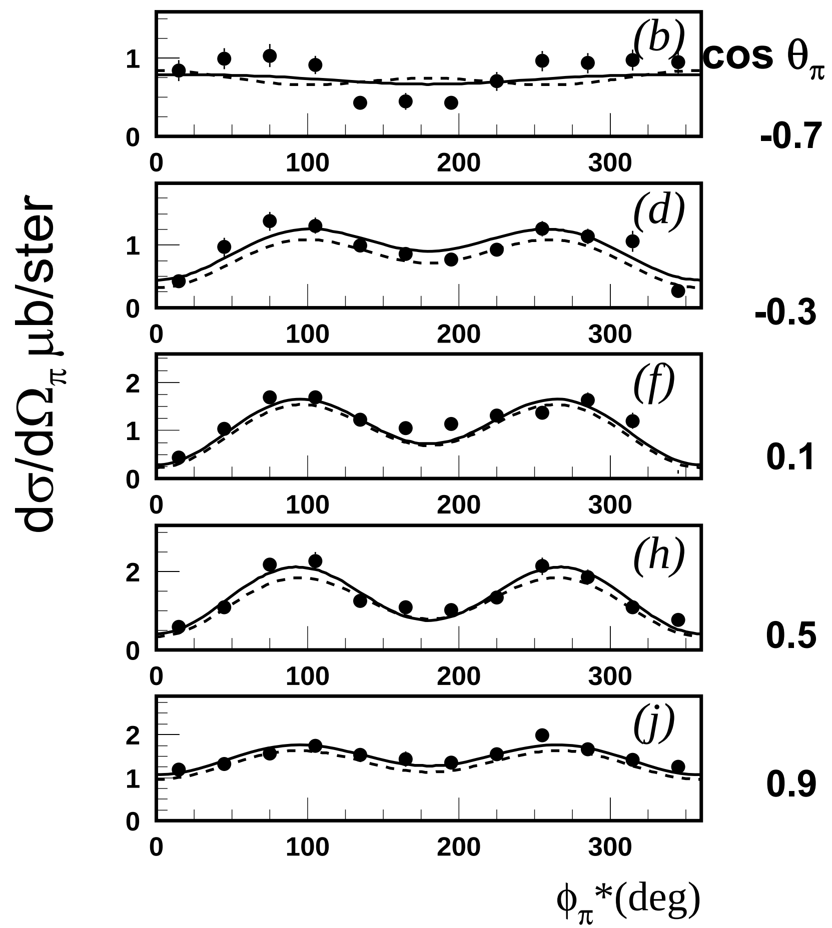


$\gamma_v p \to \pi^+ n$

K. Park et al., Phys. Rev. C91, 052014 (2015)

W=1.68 GeV
Q^2=1.8 GeV^2

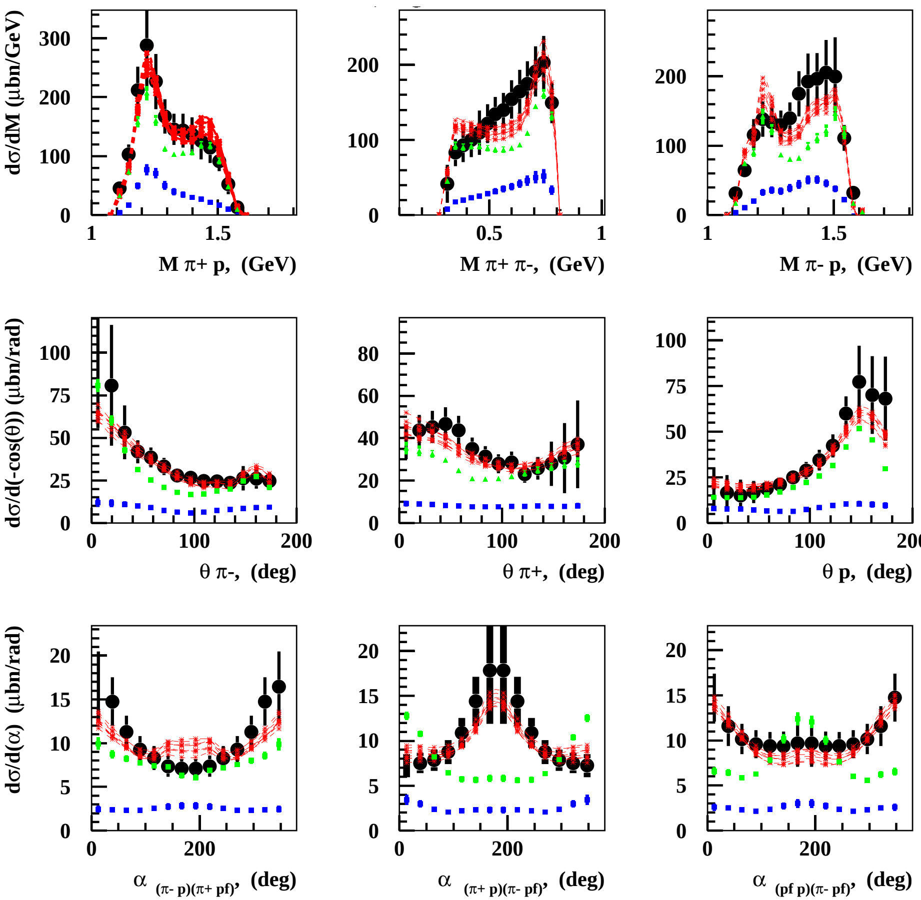
DR (solid line)
UIM (dashed line)



Resonant /Non-Resonant Contributions from the Fit of $\pi^+\pi^-p$ Photo-/Electroproduction Cross Sections within the JM Model

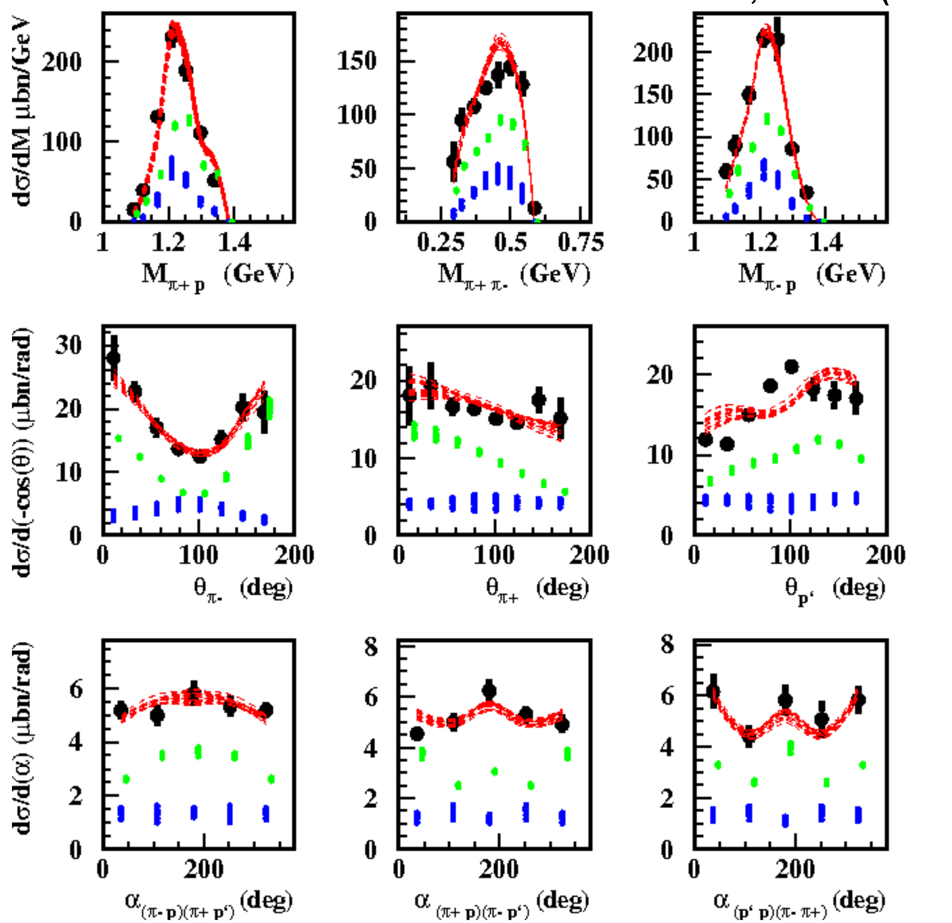
W=1.74 GeV, Q²=0. GeV²

E. N. Golovach. preliminary



W=1.51 GeV, Q²=0.38 GeV²

G. V. Fedotov et al, CLAS Coll. PRC 79, 015204 (2009)



Data uncertainties at $Q^2=0$ are dominated by systematics

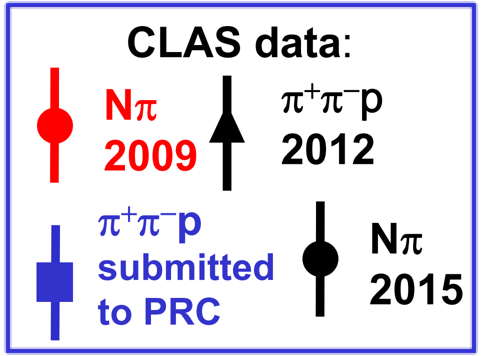
full cross sections within the JM model

Reliable isolation of the resonant cross sections is achieved

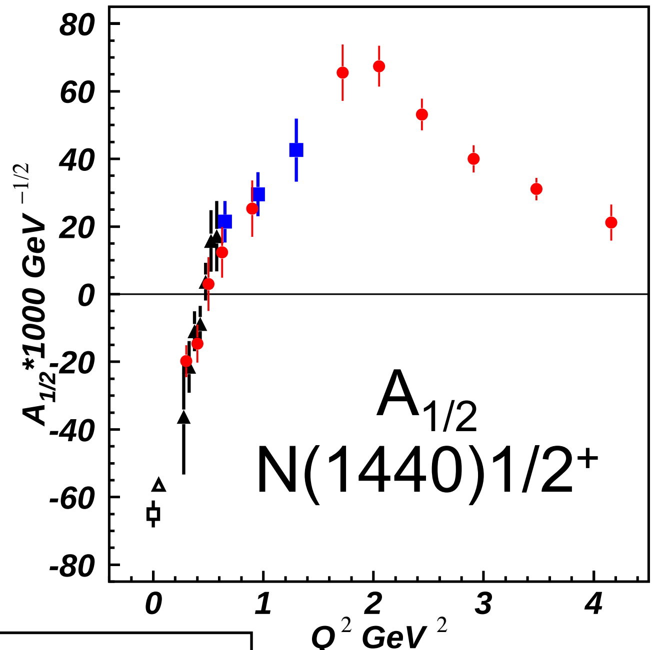
resonant part

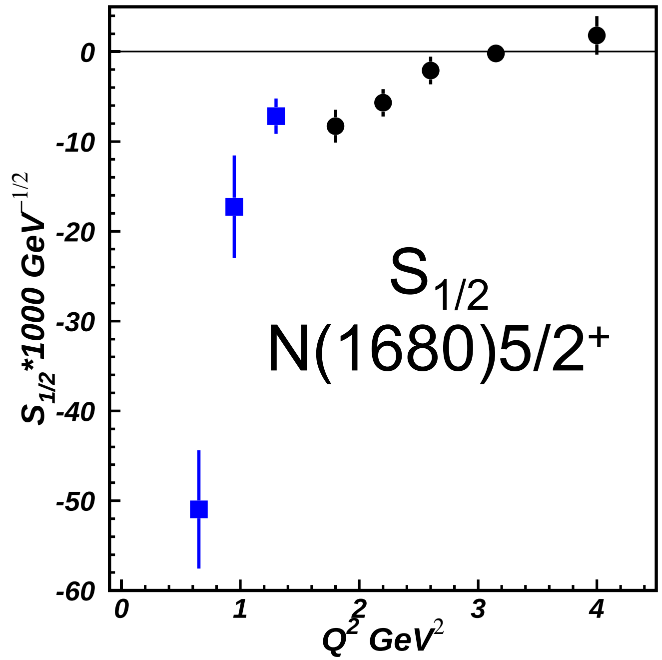
non-resonant part

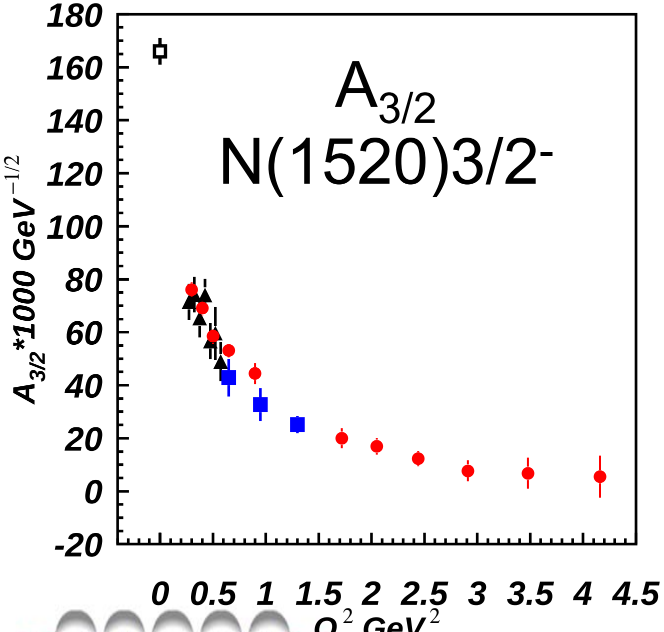
$\gamma_v NN^*$ Electrocouplings from $N\pi$ and $\pi^+\pi^- p$ Electroproduction



I.G. Aznauryan et al., Phys. Rev. C80, 055203 (2009).
V.I. Mokeev et al., Phys. Rev . C86, 035203 (2012).
K. Park et al., Phys. Rev. C91, 052014 (2015).





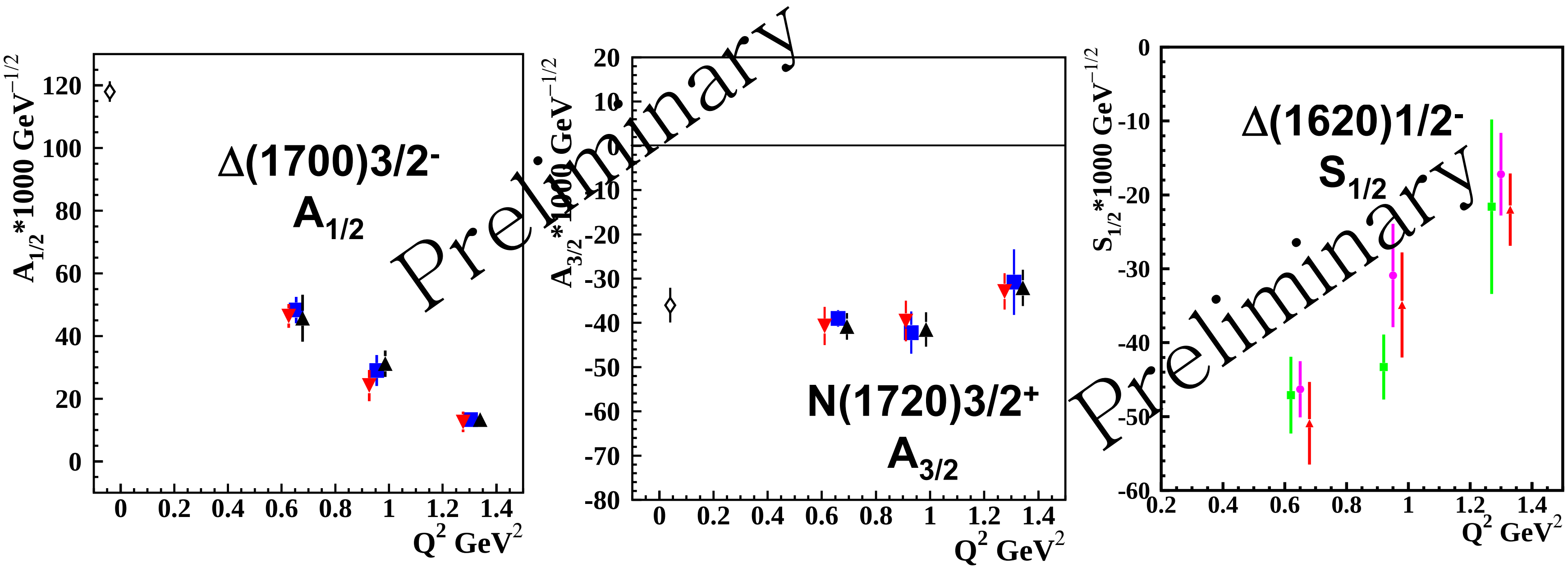


Consistent values of resonance electrocouplings from analyses of $N\pi$ and $\pi^+\pi^- p$ exclusive channels strongly support:

- **reliable electrocoupling extraction;**
- **capabilities of the reaction models to obtain resonance electrocouplings in independent analyses of these channels.**

$\gamma_v NN^*$ electrocouplingds of $N(1440)1/2^+$ and $N(1520)3/2^-$ states were published in 14' editiion of PDG.

Status and Prospects on Extraction of High-Lying N* Electrocouplings from CLAS Data



<u>Independent fits in different W-intervals:</u>

green: 1.51<W<1.61 GeV
magenta: 1.56<W<1.66 GeV
red: 1.61<W<1.71 GeV
blue: 1.66<W<1.76 GeV
black: 1.71<W<1.81 GeV

consistent electrocoupling values offer sound evidence for their reliable extraction.

$\pi^+\pi^-p$ electroproduction channel provided first preliminary results on Δ(1620)1/2-, N(1650)1/2-, N(1680)5/2+, Δ(1700)3/2- , and N(1720)3/2+ electrocouplings with good accuracy.

<u>Prospect:</u> evaluation of high-mass N* electrocouplings from independent analyses of KY channels.

Summary of the Published/Ready for Publication Results on $\gamma_v pN^*$ Electrocouplings from CLAS

Exclusive meson electroproduction channels	Excited proton states	Q^2-ranges for extracted $\gamma_v NN^*$ 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
$\pi^+\pi^- p$ obtained with the leading contribution from the OEPVAYa	$N(1440)1/2^+$, $N(1520)3/2^-$ $\Delta(1620)1/2^-$, $N(1650)1/2^-$, $N(1680)5/2^+$, $\Delta(1700)3/2^-$, $N(1720)3/2^+$, $N'(1720)3/2^+$	0.25-1.50 0.5-1.5

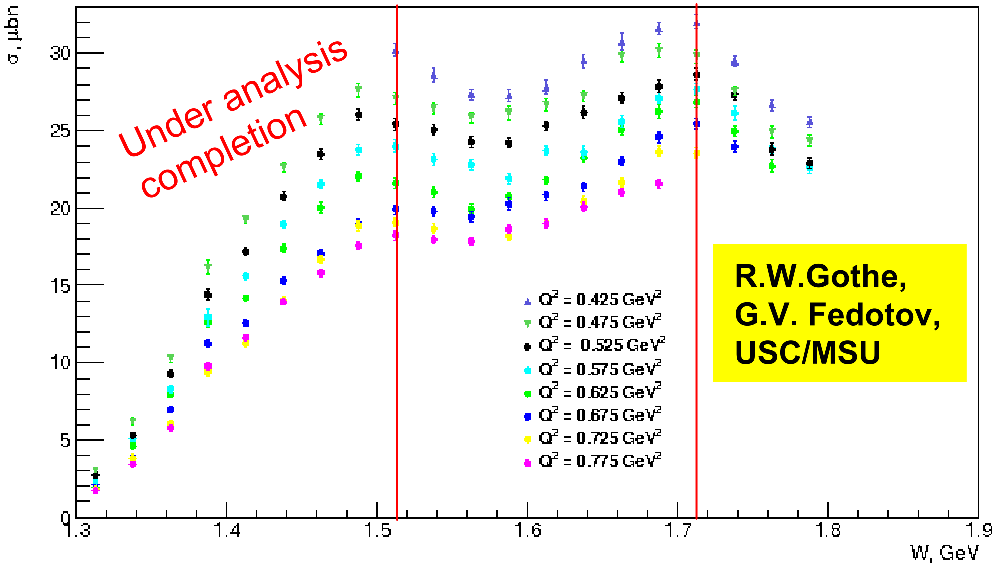
The values of resonance electrocouplings can be fond in:
https://userweb.jlab.org/~mokeev/resonance_electrocouplings/

The prospects:

•$\gamma_v pN^*$ electrocoupling of all prominent nucleon resonances in mass range M_{N^*}<2.0 GeV will be determined from independent analyses of $N\pi$, $N\pi\pi$, and KY channels;

•the web-site will be developed for evaluation of $\gamma_v pN^*$ electrocouplings for the aforementioned resonances at 0.2 GeV^2 < Q^2< 5.0 GeV^2.

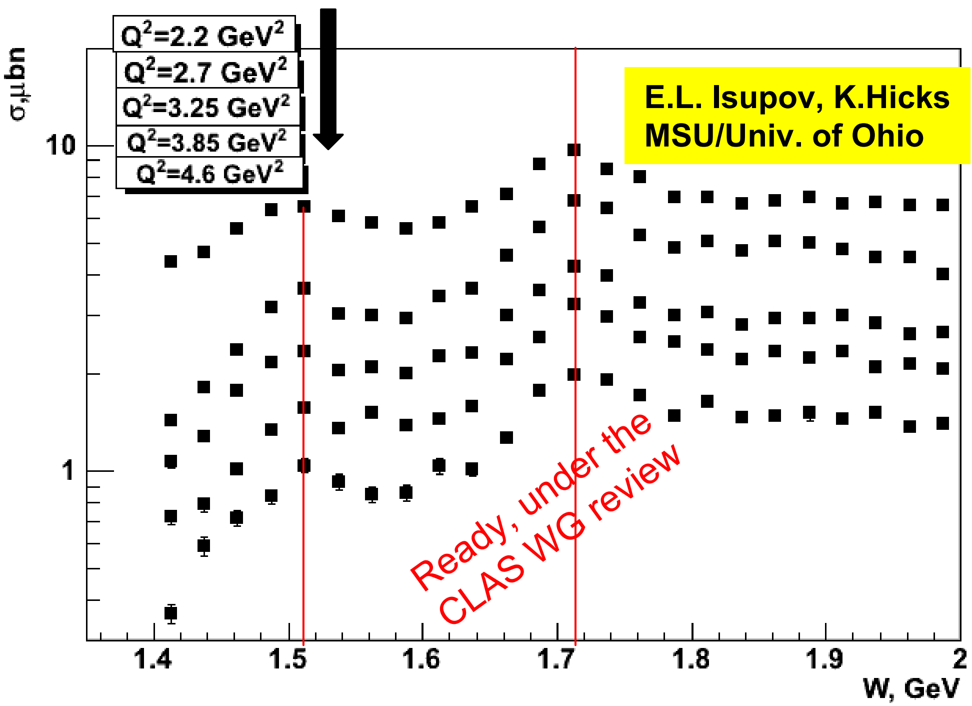
Extension of the CLAS $\pi^+\pi^-p$ Electroproduction Data



<u>Fully integrated $\pi^+\pi^-p$ electroproduction cross sections off protons</u>

•Nine 1-fold differential cross sections are available In each bin of W and Q^2 shown in the plots.

•Resonance structures are clearly seen at W ~1.5 GeV and ~1.7 GeV at 0.4< Q^2< 5.0 GeV^2 (red lines) .



<u>Analysis objectives:</u>

•Extraction of $\gamma_v NN^*$ electrocouplings and $\pi\Delta$, ρp decay widths for most N*s in mass range up to 2.0 GeV and 0.4< Q^2< 5.0 GeV^2 within the framework of JM-model.

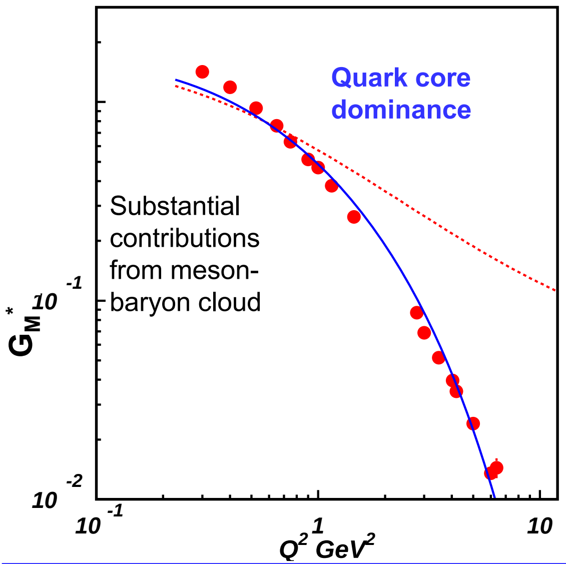
•Exploration of the signals from 3/2$^+$(1720) candidate-state (M.Ripani et al., Phys. Rev. Lett 91, 022002 (2003)) with a goal to achieve decisive conclusion on the state existence and structure.

•First results on electrocouplings of high-lying (M_{N^*}>1.6 GeV) orbital nucleon excitations and high-lying parity partners.

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

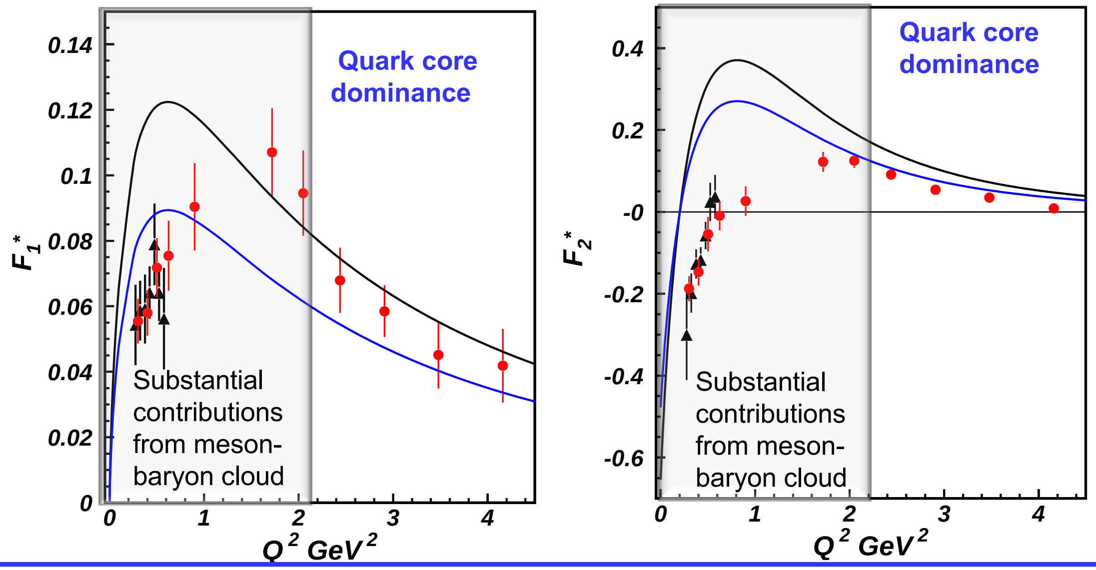
Δ(1232)3/2⁺
Jones-Scadron convention

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



N(1440)1/2⁺
Dirac F_1^* and Pauli F_2^*
N→N(1440)1/2⁺ transition form factors

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



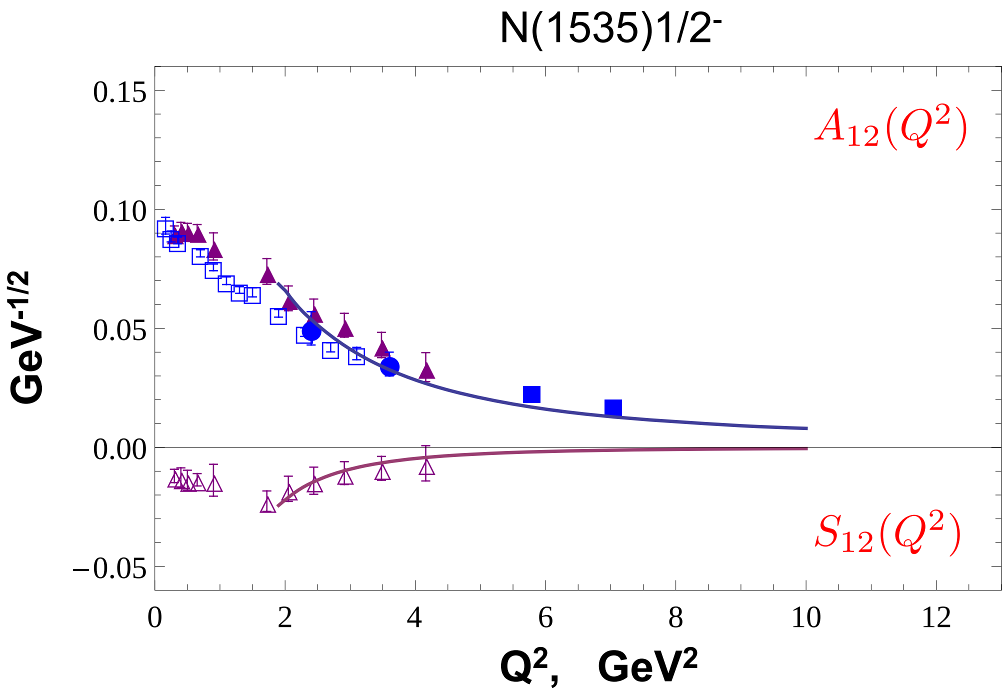
The quark core contributions to transition form factors computed in a common DSEQCD framework starting from the QCD Lagrangian:

- (red dashed line) **Contact qq interaction, frozen constituent quark mass.**
- (blue line) **Realistic qq interaction, running quark mass.**
- (black line) **Realistic qq interaction, running quark mass,**
- (blue line) **the same but multiplied by the common factor which accounts for the product of the quark core fractions in ground and N(1440)1/2⁺ states**

Good data description at Q^2>2.0 GeV² achieved with the same dressed quark mass function for the ground and excited nucleon states of distinctively different structure demonstrates for the first time the capability to probe quark mass function from the data on elastic/transition form factors.

Significant achievement in hadron physics of the last decade in collaborative experimrentalist/theorist efforts with the dominant contribution to the experimental results from the CLAS.

Relating $\gamma_v NN^*$ Electrocouplings to the first Principles of QCD within the Framework of Light Cone Sum Rule (LCSR) & Lattice QCD (LQCD) Approaches



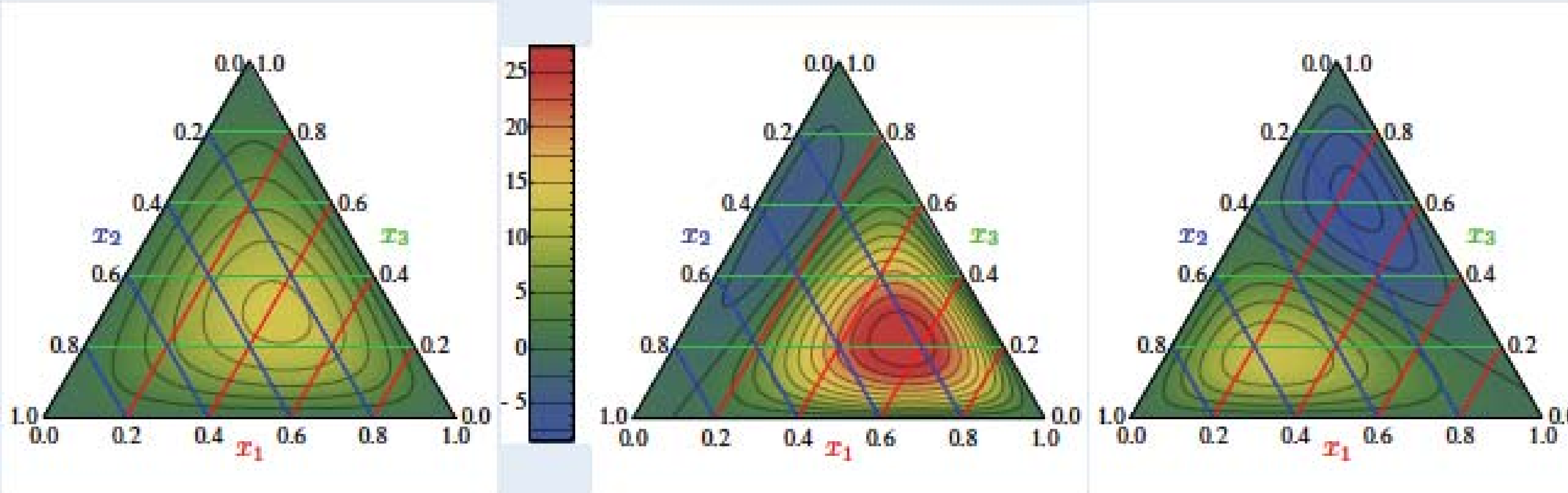
I.V. Anikin, V.M. Braun, N. Offen, Phys. Rev. D92, 014018 (2015)

The shape parameters of N(1535)1/2$^-$ leading twist quark distribution amplitude (DA) φ_{ij}, η_{ij} were fit to the CLAS electrocoupling data within LCSR , while normalization parameters λ_{1N^*}, f_{N^*} were taken from the LQCD evaluations at the central values (V.M. Braun et al., Phys. Rev D89, 094511 (2014)).

Successful description of the CLAS data at Q^2>2.0 GeV^2, where LCSR is applicable, with normalization parameters from LQCD demonstrates the approach potential of relating $\gamma_v NN^*$ electrocouplings to the first principles of QCD

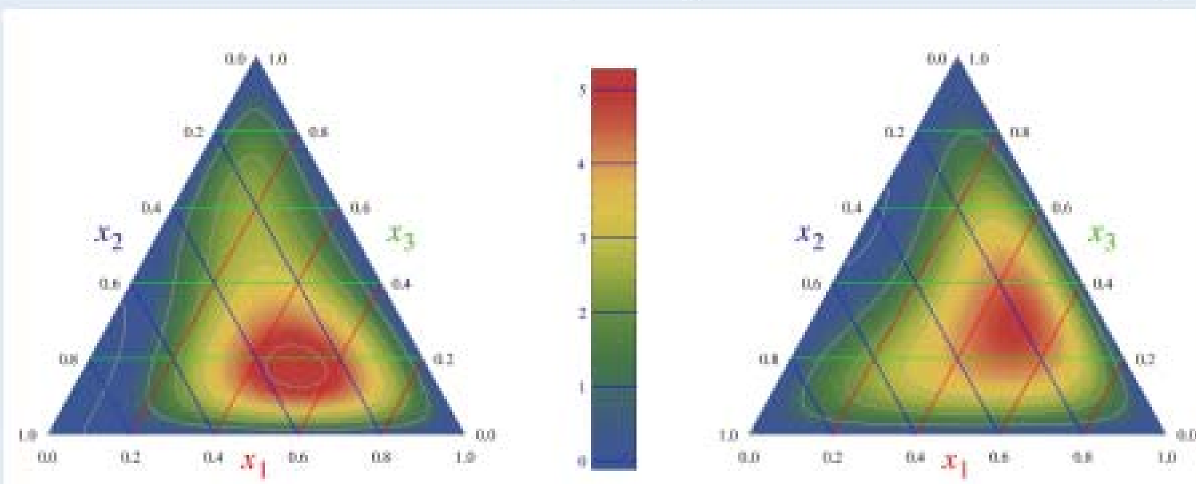
Method	$\lambda_1^N/\lambda_1^{N^*}$	$f_{N^*}/\lambda_1^{N^*}$	φ_{10}	φ_{11}	η_{10}	η_{11}
LCSR	0.633	0.027	0.36(>1)	-0.95(>1)	0.00(29)	0.94(71)
LQCD	0.633(43)	0.027(2)	0.28(12)	-0.86(10)	N./A.	N./A.

Distribution amplitudes from lattice RQCD vs. LCSRs



Nucleon $N^*(1650?) + N\pi$ $N^*(1535?)$

Nucleon DA from LCSRs for comparison (N. Offen)



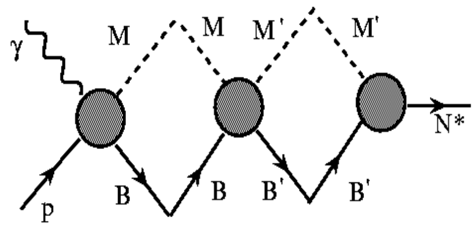
N and N(1535)1/2⁻ DA should be identical in the chiral limit.

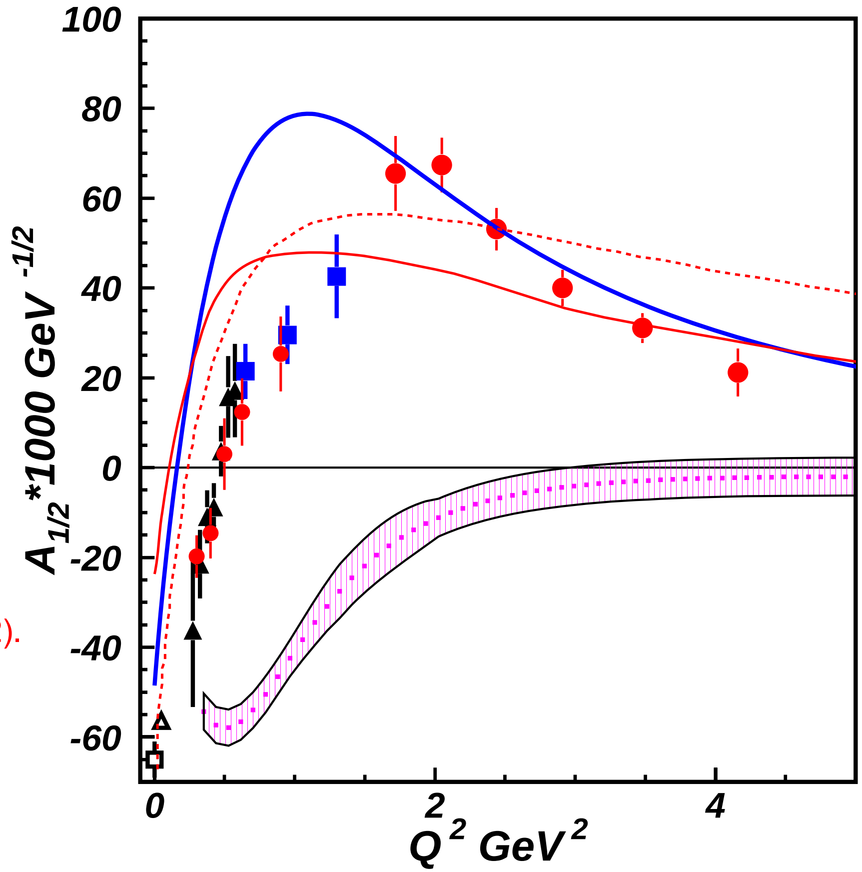
Shed light on Dynamical Chiral Symmetry Breaking

Quark Core and Meson-Baryon Cloud in the Structure of N(1440)1/2⁺ Resonance

Quark core from DSEQCD

The mechanisms of meson-baryon dressing :





Description of the N(1440)1/2⁺ $A_{1/2}$ electrocoupling by the light front quark models that incorporate the inner core and outer meson-baryon (MB) cloud:

Nπ loops MB cloud; running quark mass.
I.G .Aznauryan, V.D. Burkert, Phys. Rev. C85, 055202 (2012).

Nσ loops for MB cloud; frozen constituent quark mass.
I.T. Obukhovsky, et al., Phys. Rev. D89, 014032 (2014).

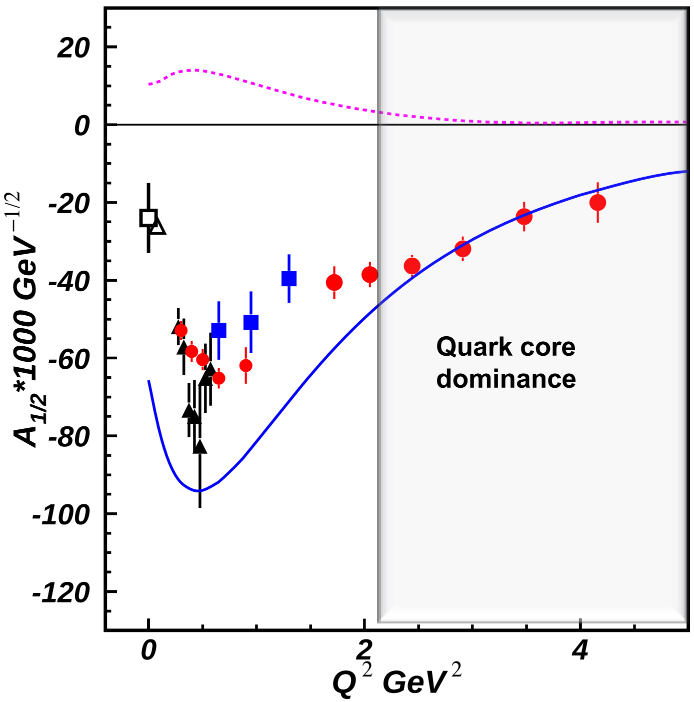
MB cloud inferred from the CLAS data as the difference between the data fit and evaluated within DSEQCD quark core

Successful description of the N(1440)1/2⁺ quark core from the QCD Lagrangian has been achieved for the first time with the framework of DSEQCD!

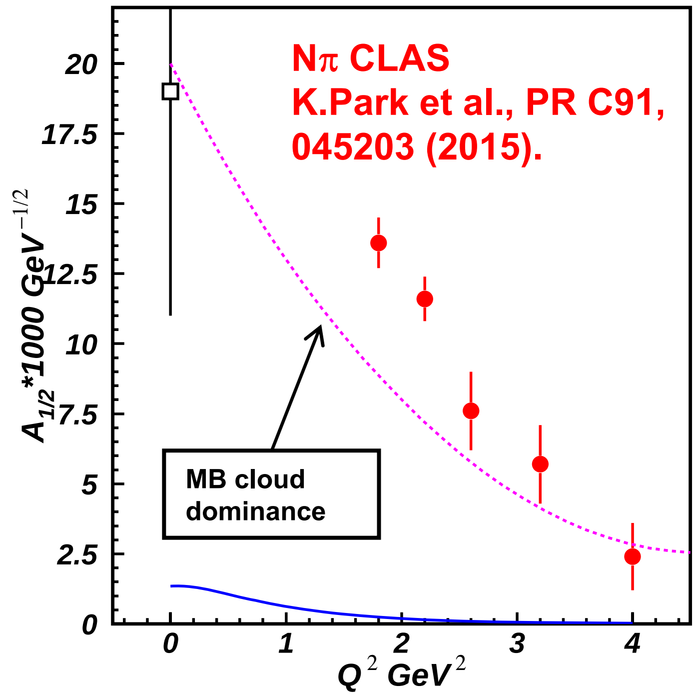
The structure of N(1440)1/2⁺ resonance is determined by complex interplay between inner core of three dressed quarks in the first radial excitation and external meson-baryon cloud.

Interplay Between Quark Core and Meson-Baryon Cloud in the Structure of Different Excited Nucleon States

N(1520)3/2⁻



N(1675)5/2⁻



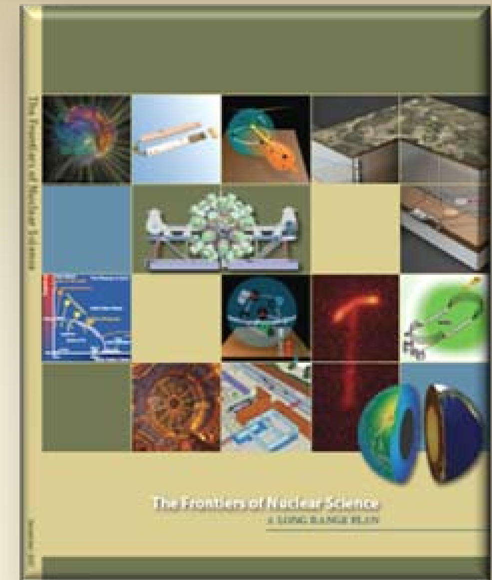
MB dressing abs. values (Argonne-Osaka).

E. Santopinto and M. M. Giannini, PRC 86, 065202 (2012).

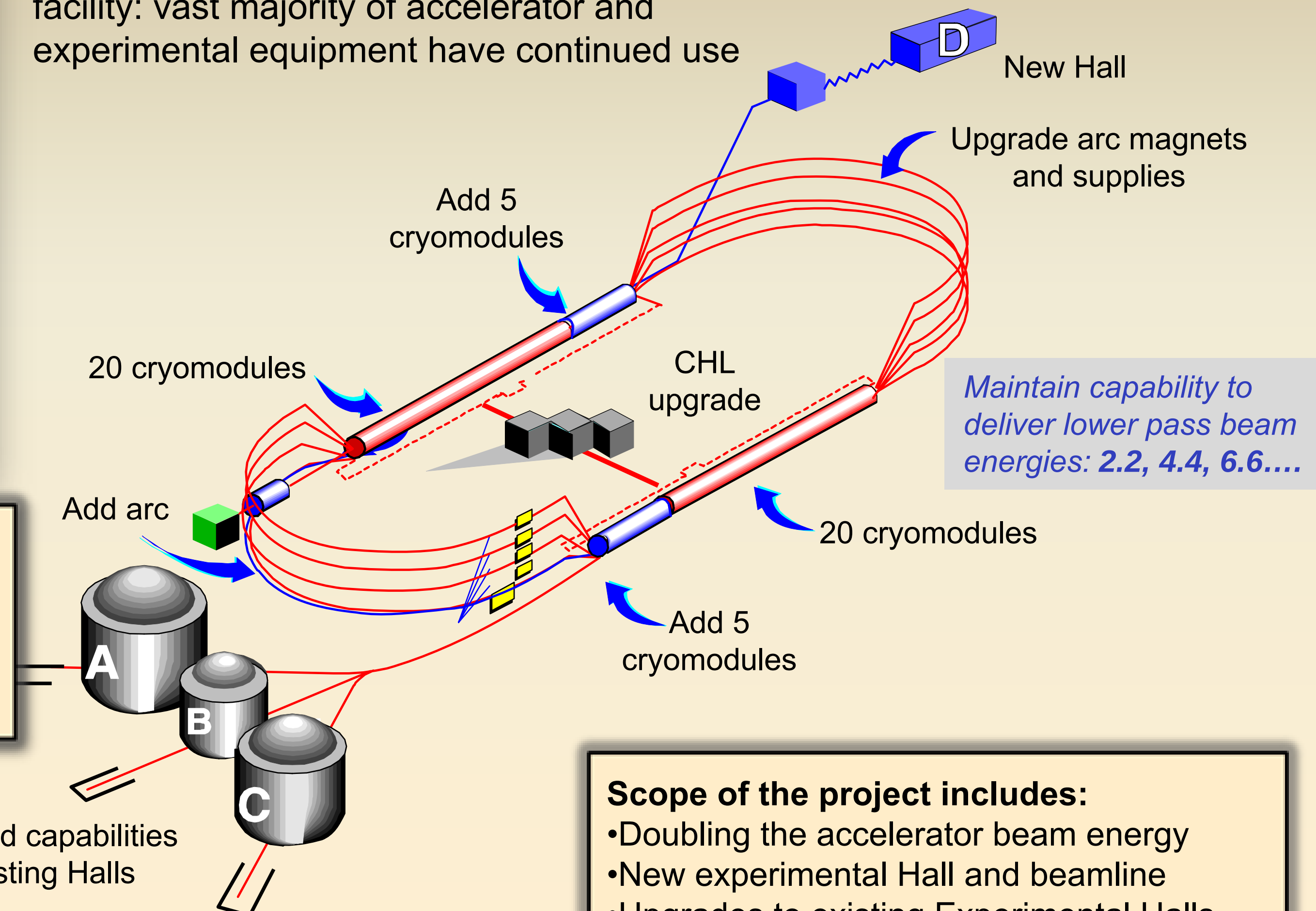
Almost direct access to:

- **quark core from the data on N(1520)3/2⁻: prospect to explore dressed quark mass function, qqG vertex, and di-quark correlations;**
- **meson-baryon cloud from the data on N(1675)5/2⁻: shed light on the transition from confined quarks in inner core to colorless mesons and baryons in N* exterior**

12 GeV Upgrade Project



Upgrade is designed to build on existing facility: vast majority of accelerator and experimental equipment have continued use



The completion of the 12 GeV Upgrade of CEBAF was ranked the highest priority in the 2007 NSAC Long Range Plan.

Scope of the project includes:
- Doubling the accelerator beam energy
- New experimental Hall and beamline
- Upgrades to existing Experimental Halls

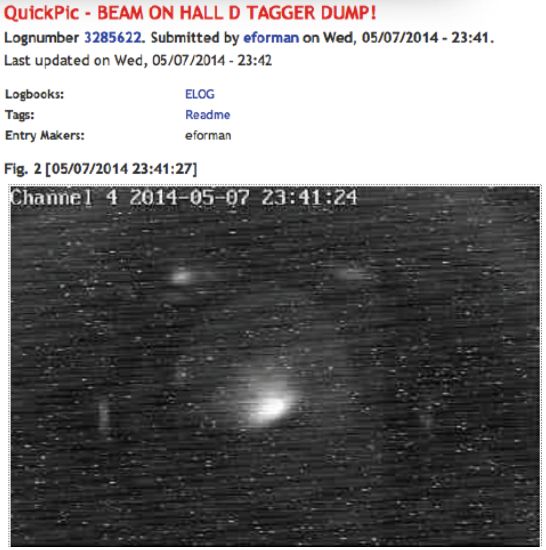
5.5 Pass: 10.5 GeV to Tagger Dump

10.5 GeV to 5C

Hall D Beamline

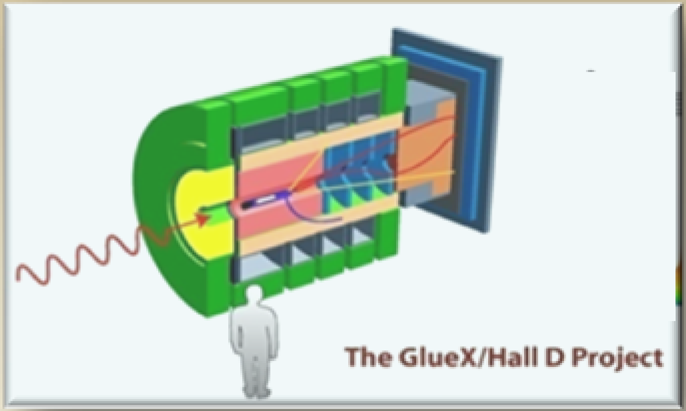
Hall D Tagger Magnet and Dump

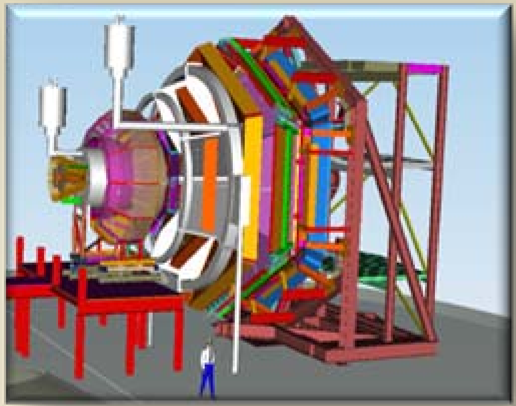
23:42
May 7
2014



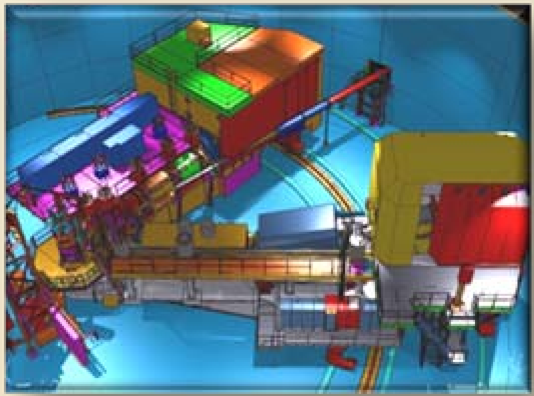
12 GeV Scientific Capabilities

Hall D – exploring origin of confinement by studying exotic mesons

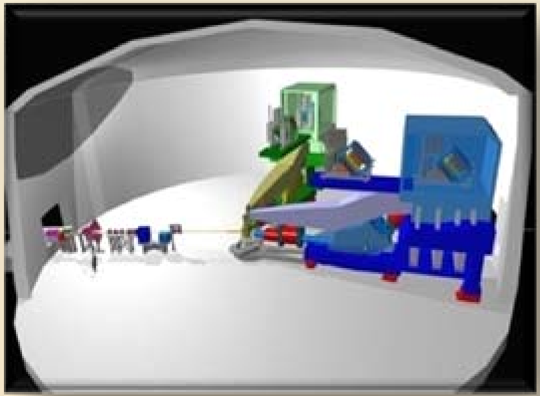




Hall B – understanding nucleon structure via generalized parton distributions, excited nucleon structure



Hall C – precision determination of valence quark properties in nucleons and nuclei



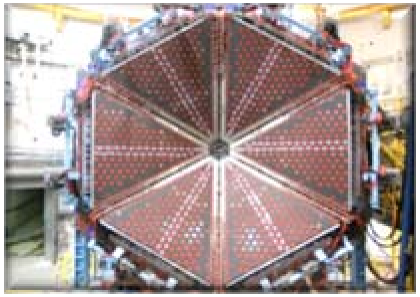
Hall A –form factors, future new experiments (e.g., SoLID and MOLLER)

12 GeV Upgrade Project Highlights

12 GeV Upgrade progress on many fronts

<u>Accelerator 99% complete</u>:
cryomods, cryogenics, beam transport done

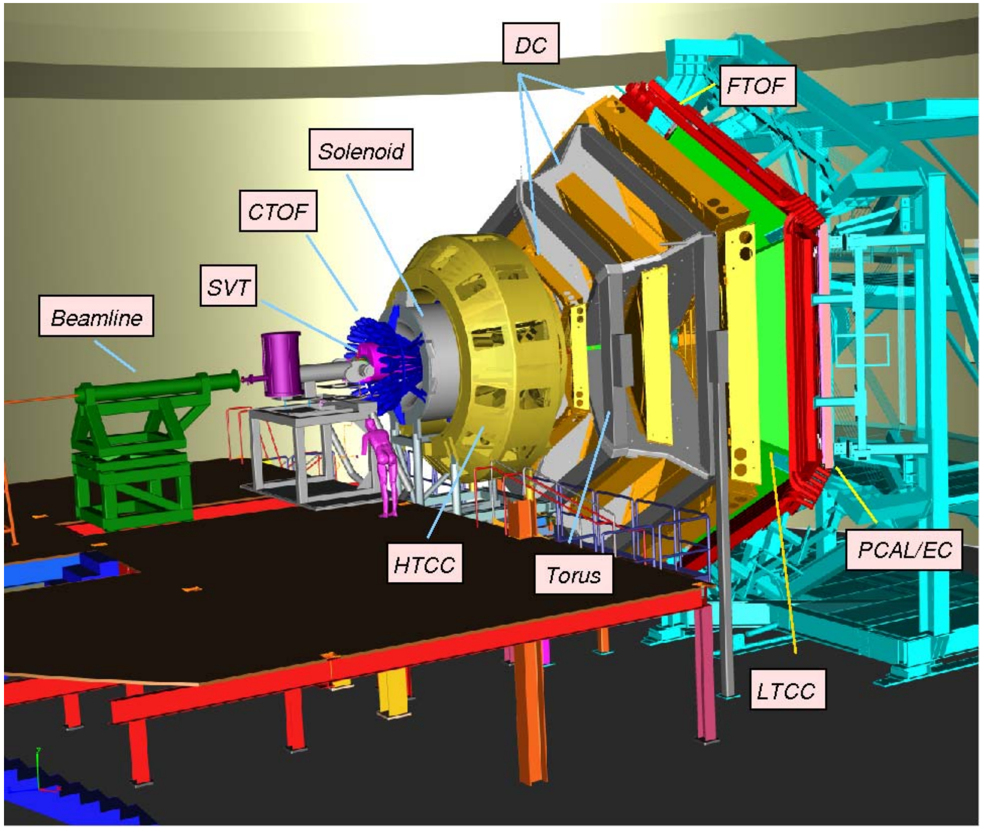
<u>Hall B 73% complete</u>:
PCAL/FTOF installed ; Torus coil winding

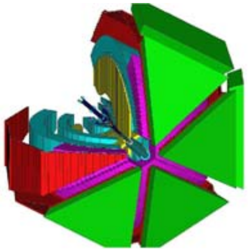


<u>Hall D 97% complete</u>:
on track for beam commissioning Fall 2014

<u>Hall C 73% complete</u>:
shield house installed ; Dipole coil winding

CLAS12 Spectrometer



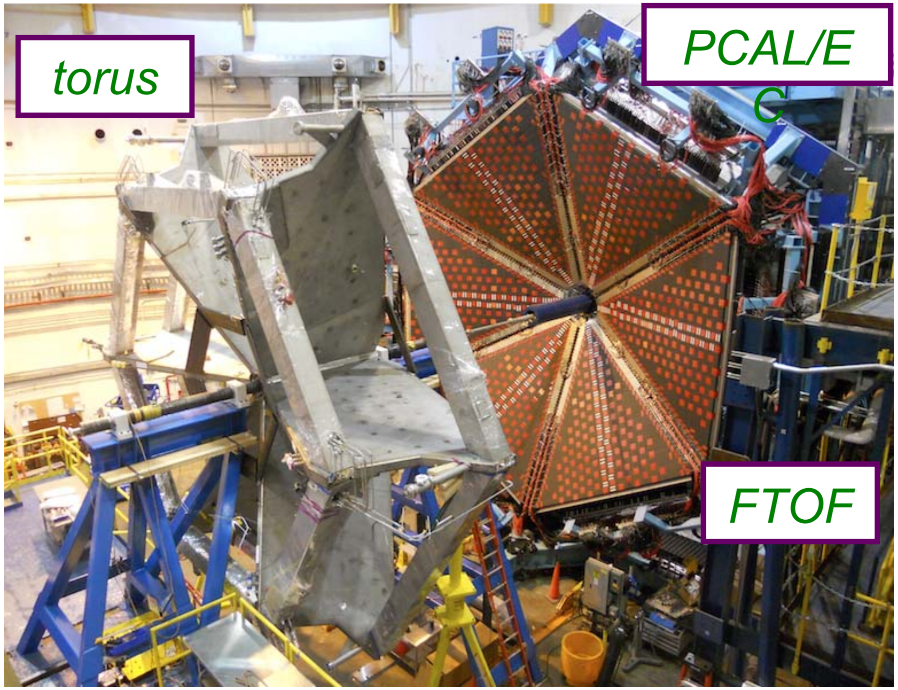


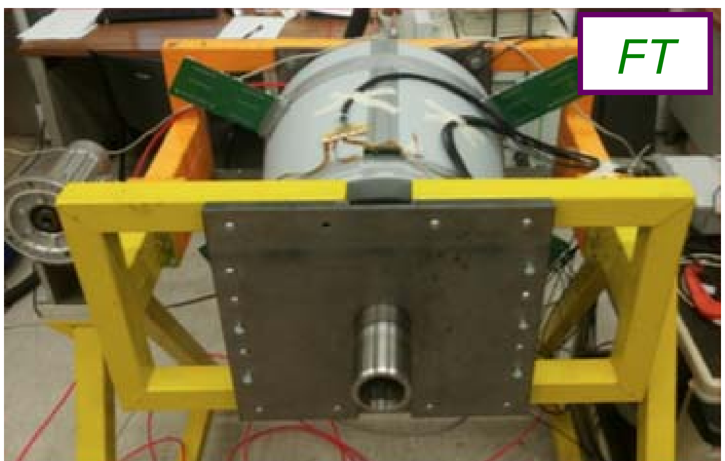
CLAS Spectrometer: 1997 - 2012

CLAS12 Specifications

	Forward	Central
Angular coverage	$5^o - 35^o$	$35^o - 135^o$
Momentum resolution	$\delta p/p < 1\%$	$\delta p/p < 5\%$
θ resolution	1 mrad	5 – 10 mrad
ϕ resolution	1 mrad/sinθ	5 mrad/sinθ
PID:		
π/K	4σ to 2.8 GeV	3σ to 0.6 GeV
K/p	4σ to 4.8 GeV	3σ to 1.0 GeV
π/p	4σ to 5.4 GeV	3σ to 1.2 GeV
Calorimeter resolution	$\sigma_E \sim 0.1\sqrt{E}$	
Luminosity	10^{35} cm^{-2}s^{-1}	

CLAS12 Photographs





CLAS12 N* Program

E12-09-003	E12-06-108A
Nucleon Resonance Studies with CLAS12	KY Electroproduction with CLAS12
Burkert, Mokeev, Stoler, Joo, Gothe, Cole	*Carman, Mokeev, Gothe*

- Measure exclusive electroproduction cross sections from an unpolarized proton target with polarized electron beam for $N\pi$, $N\eta$, $N\pi\pi$, KY:

  E_b = 11 GeV, $Q^2 = 3 \rightarrow 12$ GeV^2, $W \rightarrow 3.0$ GeV with the almost complete coverage of the final state phase space

- Key Motivations:

  Study the structure of all prominent N states in the mass range up to 2.0 GeV vs. Q^2 up to 12 GeV^2.*

  CLAS12 is the only facility foreseen in the world capable to map-out N quark core under almost negligible contributions from meson-baryon cloud*

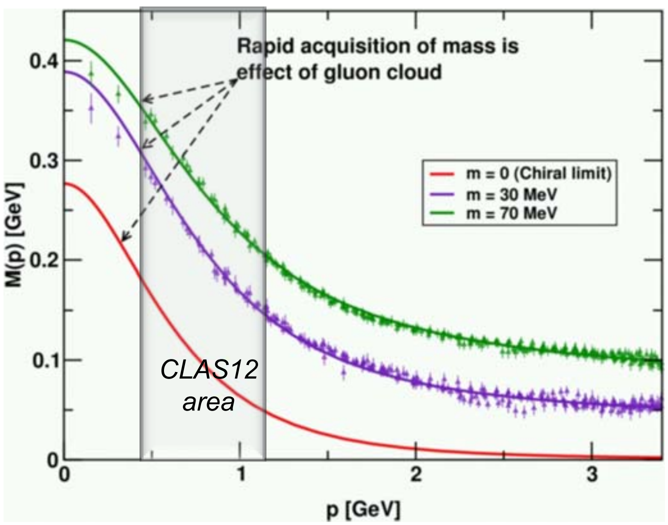
  A unique opportunity to probe dressed quark mass function in the transition from confinement to pQCD regime and to explore the nature of confinement and its emergence from QCD from the results on transition N→N form factors/electrocouplings*

The experiments will start in the first year of running with the CLAS12 detector.

N* Structure at High Photon Virtualities in Exploration of Strong Interaction

Dressed quark mass function

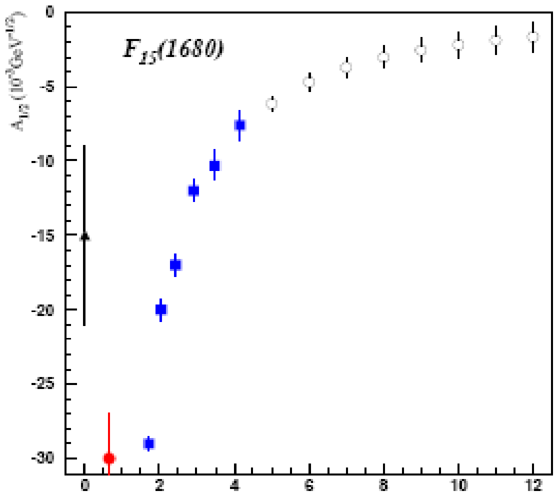
C.D. Roberts, Prog. Part. Nucl. Phys. (2008) 50.



Resonance electrocouplings

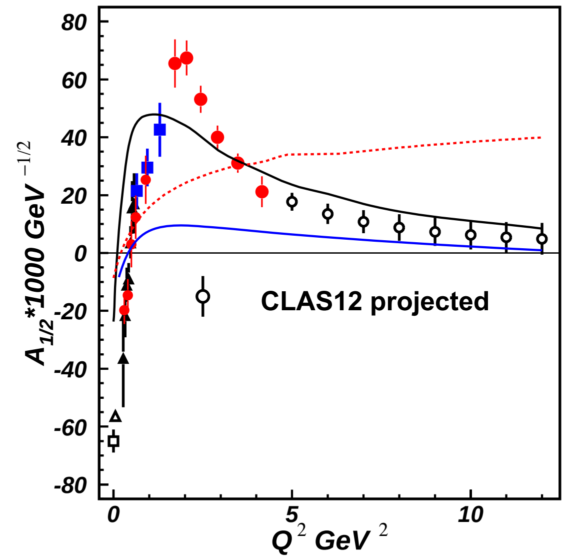
(available from CLAS and expected from CLAS12)

N(1680)5/2 +



N(1440)1/2 +

D.J. Wilson et al., Phys. Rev C85 (2012) 045205 DSEQCD.
I.G. Aznauryan & V.D. Burkert, Phys. Rev. C85 (2012) 055202 LF QM.



Opportunity to probe dressed quark mass function in the transition from quark-gluon confinement to pQCD regimes for the first time.

Consistent results on quark mass function from electrocouplings of different resonances at Q^2 > 5 GeV^2 will prove reliable access to this fundamental quantity.

DSEQCD : ***(quark core only)*** ······ *constant quark mass.*

Light Front Quark Model ***(quark core & MB cloud)*** —— *running quark mass from DSEQCD.*

Important direction in the recommendations of the 2014 Town Meeting on QCD and Hadron physics for the next US Long Range Plan, S.J. Brodsky et al., arXiv:1520.05728 [hep-ph].

Contact person: Volker D. Burkert

A Letter of Intent to the Jefferson Lab PAC43

Search for Hybrid Baryons with CLAS12 in Hall B

Annalisa D'Angelo,[1,2] Ilaria Balossino,[11] Luca Barion,[11] Marco Battaglieri,[3] Vincento Bellini,[12] Volker Burkert,[4] Simon Capstick,[5] Daniel Carman,[4] Andrea Celentano,[3] G. Ciullo,[11] Marco Contalbrigo,[11] Volker Credé,[5] Raffaella De Vita,[3] E. Fanchini,[3] Gleb Fedotov,[6] A. Filippi,[10] Evgeny Golovach,[6] Ralf Gothe,[7] Boris S. Ishkhanov,[6,13] Evgeny L. Isupov,[6] Valeri P. Koubarovski,[4] Lucilla Lanza,[2] P. Lenisa,[11] Francesco Mammoliti,[12] Victor Mokeev,[4,6] A. Movsisyan,[11] Mikhail Osipenko,[3] Luciano Pappalardo,[11] Marco Ripani,[3] Allesando Rizzo,[2] Jan Ryckebusch,[8] Iuliia Skorodumina,[7,13] Concetta Sutera,[12] Adam Szczepaniak,[9,4] Mauro Taiuti,[3] M. Turisini,[11] Maurizio Ungaro,[4] and Veronique Ziegler[4]

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[4]*Thomas Jefferson National Accelerator Facility, Newport News, Virginia 23606, USA*
[5]*Florida State University, Tallahassee, Florida 32306, USA*
[6]*Skobeltsyn Institute of Nuclear Physics, Lomonosov Moscow State University, 119234 Moscow, Russia*
[7]*University of South Carolina, Columbia, South Carolina 29208, USA*
[8]*Gent University, Gent, Netherland*
[9]*Indiana University, Nuclear Theory Center, Bloomington, Indiana*
[10]*INFN, Sezione di Torino, Torino, Italy*
[11]*INFN Ferrara e Universitá di Ferrara, Italy*
[12]*INFN, Sezione di Catania, Catania, Italy*
[13]*Physics Department at Lomonosov Moscow State University, Leninskie Gory, Moscow 119991, Russia.*

(Dated: May 17, 2015)

Recommendation:

The PAC encourages the preparation of a full proposal. However, we emphasize that the 11 GeV running should be put forward as a **Run Group Proposal**, if it is indeed to run in parallel with other approved experiments. Further, the additional beam time at 6.6 and 8.8 GeV must be considered as a **separate proposal** that may include other measurements that could be carried out with the additional beam time.

Signature of the hybrid-baryons:

(qqq)g

New baryon state in the mass range from 2.1 GeV to 2.4 GeV of spin-parity $1/2^+$ or $3/2^+$

qqq-configuration should be in {8}-color state

⇩

Peculiar Q^2-dependence of hybrid-baryon electro-couplings

Models for electrocoupling extraction:

Ghent, JPAC, BnGa, JM

Flagship experiment for the studies of the N* structure at $0.05\ GeV^2 < Q^2 < 1.0\ GeV^2$

Run Group Schedule – Tentative 6/20

Run Group	Days	2015	2016	2017	2018	2019	2020	20
All Run Groups	**936**		CND MM FT	BONUS RICH	Long. PT		Trans. PT	**525**
HPS	180*	3	15+					
PRad	15*		15					
CLAS12 KPP				**15**				
RG-A (proton)	139*			**20 50**				
RG-F (BoNuS)	42*				**40**			
RG-B (deut.)	90*				**45**			
RG-C (NH_3)	120				**15**	**45**		
RG-C-b (ND_3)	65					**35**		
RG-E (Hadr.)	60					**20**	**15**	
RG-G (TT)	110*						**55**	
RG-D (CT)	60						**30**	

N* studies

NSAC Long Range Plan 2015

4 recommendations

RECOMMENDATION I

The progress achieved under the guidance of the 2007 Long Range Plan has reinforced U.S. world leadership in nuclear science. The highest priority in this 2015 Plan is to capitalize on the investments made.

- *With the imminent completion of the CEBAF 12-GeV Upgrade, its forefront program of using electrons to unfold the quark and gluon structure of hadrons and nuclei and to probe the Standard Model must be realized.*
- *Expeditiously completing the Facility for Rare Isotope Beams (FRIB) construction is essential. Initiating its scientific program will revolutionize our understanding of nuclei and their role in the cosmos.*
- *The targeted program of fundamental symmetries and neutrino research that opens new doors to physics beyond the Standard Model must be sustained.*
- *The upgraded RHIC facility provides unique capabilities that must be utilized to explore the properties and phases of quark and gluon matter in the high temperatures of the early universe and to explore the spin structure of the proton.*

Conclusions

- High quality meson electroproduction data from CLAS allowed us to determine the electrocouplings of most well-established resonances in mass range up to 1.8 GeV from analyses of π^+n, π^0p, ηp and $\pi^+\pi^-p$ electroproduction channels. Consistent electrocoupling values obtained independently from $N\pi/N\pi\pi$ exclusive channels demonstrated reliable electrocoupling extraction and capabilities of the developed reaction models to determine N*-parameters from independent analyses of $N\pi/N\pi\pi$ exclusive electroproduction.

- Physics analyses of the CLAS results on resonance electrocouplings revealed the structure of N*-states at $Q^2<5.0$ GeV^2 as complex interplay between meson-baryon and quark degrees of freedom.

- Successful description of elastic and transition form factors to different low-lying resonances achieved at $Q^2>2.5$ GeV^2 within the framework of DSEQCD demonstrated promising opportunity to probe dressed quark mass function getting an access to the essence of non-perturbative strong interaction and its emergence from QCD.

- First results on N(1535)$1/2^-$ quark distribution amplitudes (DA) have recently become available from analyses of the CLAS electrocoupling data within the framework of the Light Cone Sum Rules and Lattice QCD offering another promising avenue of relating resonance electrocouplings to the first principles of QCD.

Outlook

- **After 12 GeV Upgrade CLAS12 will be only available facility worldwide capable of obtaining electrocouplings of all prominent N* states at still unexplored ranges of low photon virtualities down to 0.05 GeV^2 and highest photon virtialities ever achieved for exclusive reactions from 5.0 GeV^2 to 12 GeV^2 from the measurements of exclusive Nπ, $\pi^+\pi^-$p, and KY electroproduction.**

- **The expected results will allow us:**
  a) search for hybrid baryons;
  b) establish the existence of new baryon states based on the fits of photo-/ electroproduction data with Q^2-independent N* hadronic parameters;
  c) explore the emergence of meson-baryon cloud from quark-gluon confinement and di-quark correlations;
  d) access quark distribution amplitudes in N* states;
  e) to probe the dressed quark mass function at the distance scales where the transition from quark-gluon confinement to pQCD regime is expected, <u>addressing the most challenging problems of the Standard Model on the nature of >98% of hadron mass and quark-gluon confinement.</u>

- **Development of the reaction models for extraction of γ_vpN* electrocouplings at Q^2>5.0 GeV^2 accounting for the quark d.o.f in non-resonant amplitudes is <u>urgently</u> needed for support of N* Program with CLAS12!**

- **Success of N* Program with the CLAS12 <u>strongly depends from productive synergy between experiment/phenomenology/theory.</u> It will be very beneficial for Jefferson Lab and hadron physics community worldwide.**

Next Step to the Future

2010 NRC Decadal Study

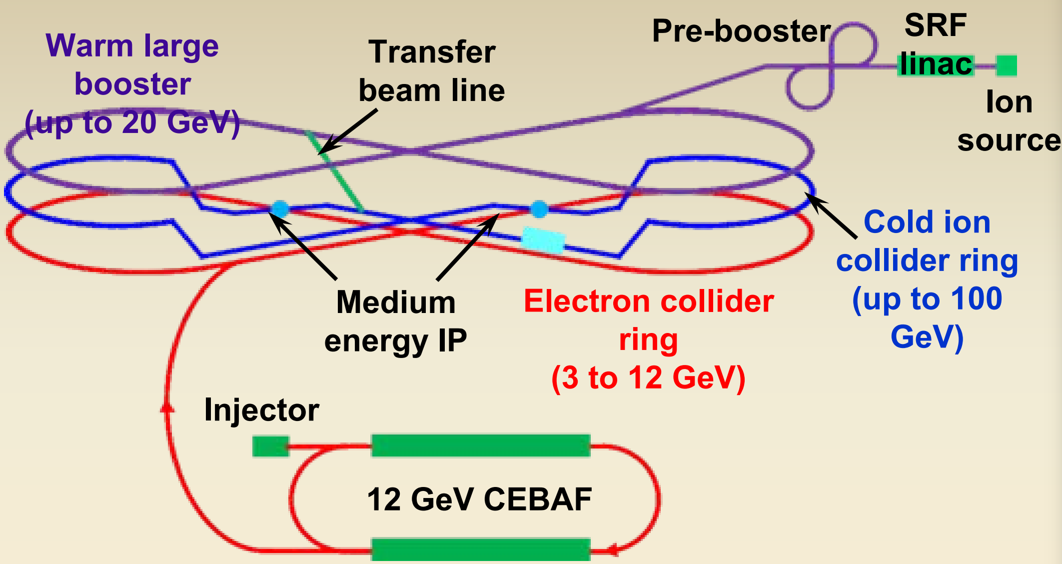
BOARD ON
PHYSICS AND ASTRONOMY
Building the foundation for the future

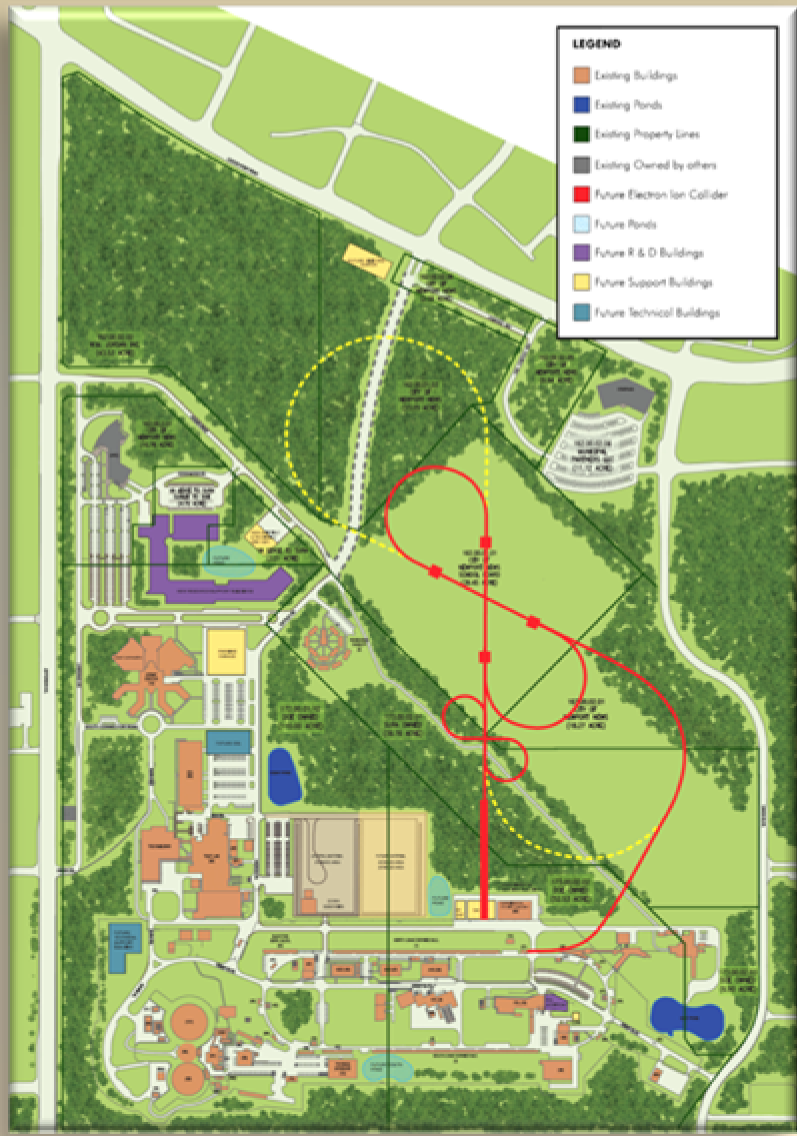
The prospects of an electron-ion collider

Finding: An upgrade to an existing accelerator facility providing the capability of colliding nuclei and electrons at forefront energies would be unique for studying new aspects of quantum chromodynamics and, in particular, would yield new information on the role of gluons in protons and nuclei. An electron-ion collider is currently a subject of study as a possible future facility

Recommendation: Investment in accelerator and detector research and development for an electron-ion collider should continue. The science opportunities and the requirements for such a facility should be carefully evaluated in the next Nuclear Science Long Range Plan.

Medium Energy EIC@JLab





JLab Concept

- MEIC:
  - 3-12 GeV on 20-100 GeV ep/eA collider
  - fully-polarized, longitudinal and transverse
  - luminosity: up to few x 10^{34} e-nucleons cm^{-2} s^{-1}
- Upgradable to higher energies (250 GeV protons)

Design Features: High Luminosity

- Follow a proven concept: KEK-B @ 2×10^{34} /cm^2/s
  - Based on *high bunch repetition rate CW colliding beams*
  - Uses crab crossing

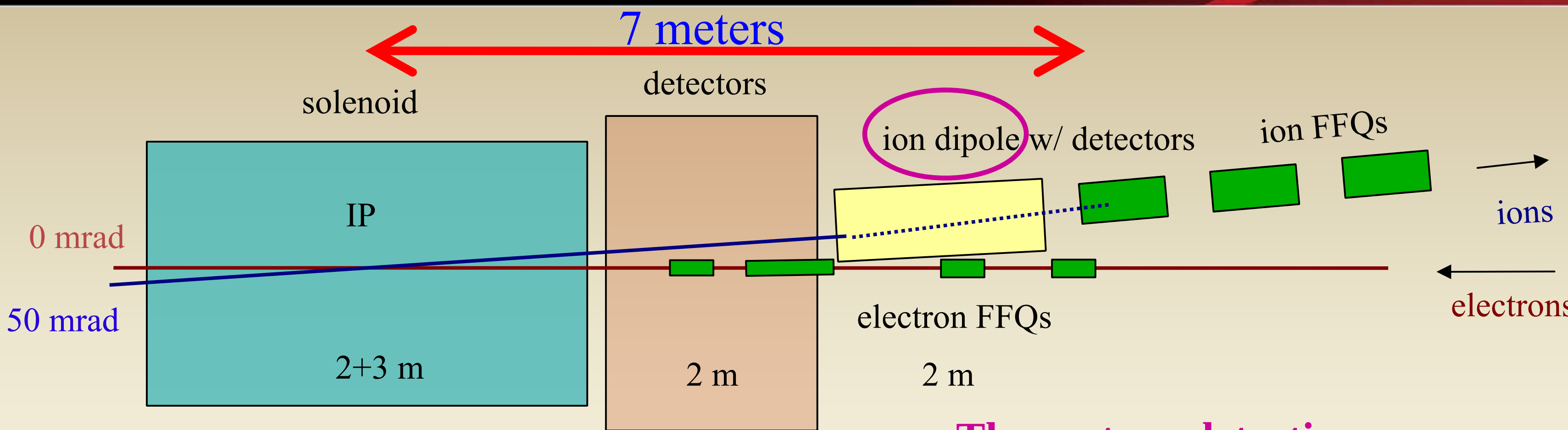
		KEK-B	MEIC	
Repetition rate	MHz	**509**	**748.5**	• high bunch repetition rate
Particles per bunch (e^-/e^+) or (**p**/e^-)	10^{10}	3.3 / 1.4	**0.42** / 2.5	• small bunch charge
Beam current	A	1.2 / 1.8	0.5 / 3	
Bunch length	cm	0.6	1 / 0.75	• short bunch length (σ_z)
Horizontal & vertical β*	cm	56 / 0.56	10/2 to 4/0.8	• small β^* ($\beta^* \sim \sigma_z$)
Beam energy (e^-/e^+) or (p/e^-)	GeV	8 / 3.5	60 / 5	
Luminosity per IP, 10^{34}	cm^{-2}s^{-1}	2	0.56 ~ 1.4	

- MEIC aims to replicate this concept in colliders w/ hadron beams
  - The CEBAF electron beam already possesses a high bunch repetition rate
  - **Add ion beams from a new ion complex to match the CEBAF electron beam**

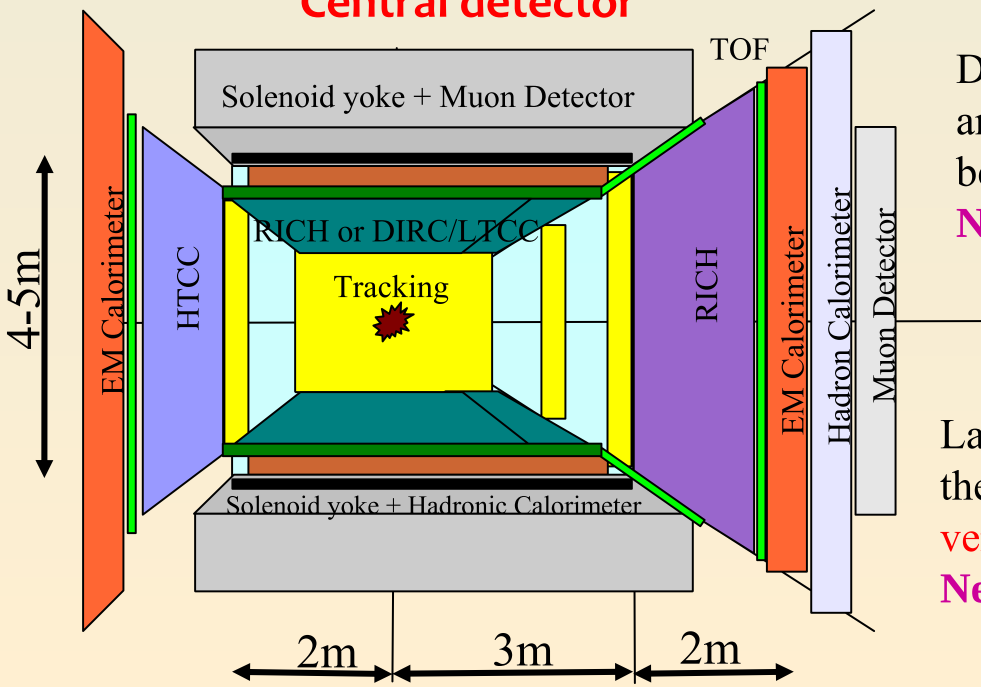
MEIC Point Design Parameters

Detector type		Full acceptance		high luminosity & Large Acceptance	
		Proton	Electron	Proton	Electron
Beam energy	GeV	60	5	60	5
Collision frequency	MHz	750	750	750	750
Particles per bunch	10^{10}	0.416	2.5	0.416	2.5
Beam Current	A	0.5	3	0.5	3
Polarization	%	> 70	~ 80	> 70	~ 80
Energy spread	10^{-4}	~ 3	7.1	~ 3	7.1
RMS bunch length	mm	10	7.5	10	7.5
Horizontal emittance, normalized	µm rad	0.35	54	0.35	54
Vertical emittance, normalized	µm rad	0.07	11	0.07	11
Horizontal and vertical β*	cm	10 and 2	10 and 2	4 and 0.8	4 and 0.8
Vertical beam-beam tune shift		0.014	0.03	0.014	0.03
Laslett tune shift		0.06	Very small	0.06	Very small
Distance from IP to 1st FF quad	m	7	3.5	4.5	3.5
Luminosity per IP, 10^{33}	$cm^{-2}s^{-1}$	5.6		14.2	

MEIC: Full Acceptance Detector



Central detector



Three-stage detection

Detect particles with angles down to 0.5° before ion FFQs.
Need 1-2 Tm dipole.

Detect particles with angles below 0.5° beyond ion FFQs and in arcs.
Need 4 m machine element free region

Very-forward detector
Large dipole bend @ 20 meter from IP (to correct the 50 mr ion horizontal crossing angle) allows for very-small angle detection (0.1-0.3°).
Need 20 m machine element free region

Back up

First Interpretation of the Structure at W~1.7 GeV in $\pi^+\pi^-p$ Electroproduction

The JM03 analysis of <u>three of nine</u> one-fold differential cross sections (*M.Ripani et al., Phys. Rev. Lett. 91, 022002 (2003)*).

conventional states only, consistent with PDG 02.

implementing $3/2^+$(1720) candidate or conventional states only with different than in PDG 02 N(1720)$3/2^+$ $N\pi\pi$ decays.

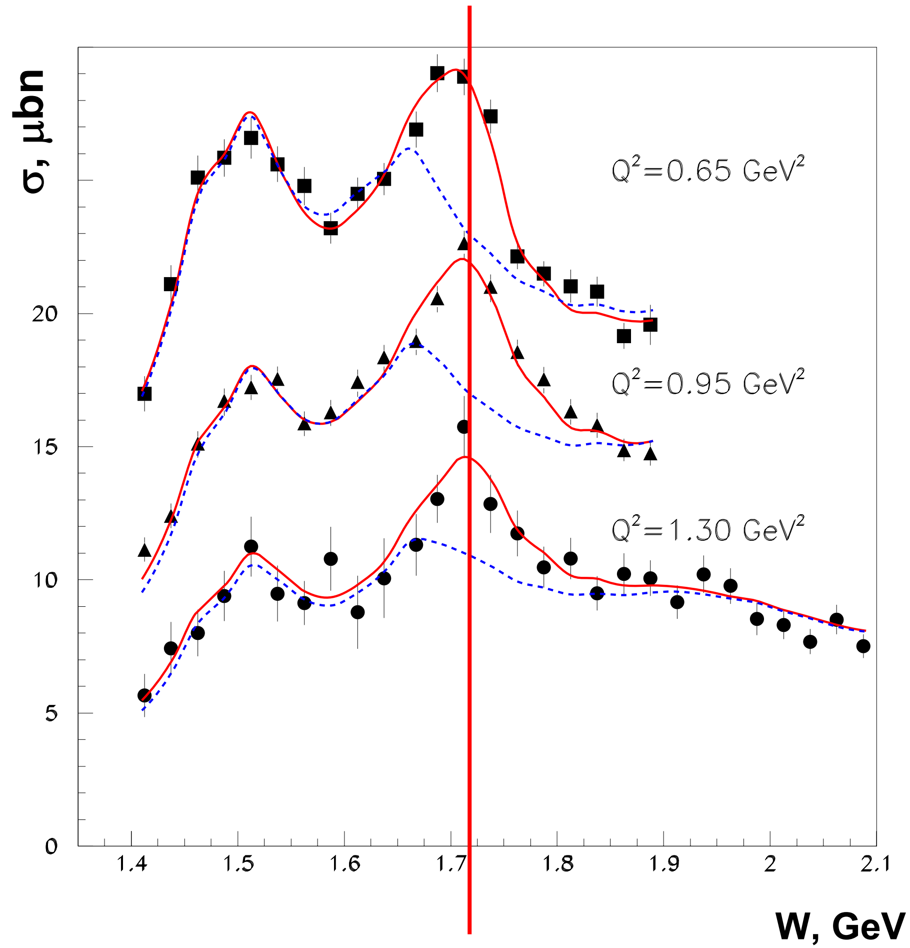
<u>Two equally successful ways for the data description:</u>

different than in PDG 02' N(1720)$3/2^+$ $N\pi\pi$ hadronic decay widths:

	Γ_{tot}, MeV	BF($\pi\Delta$) %	BF(ρp) %
N(1720)$3/2^+$ decays fit to the CLAS $N\pi\pi$ data	114±19	63±12 75±12 (BnGa12)	19±9
N(1720)$3/2^+$ PDG 02'	150-300	<20	70-85

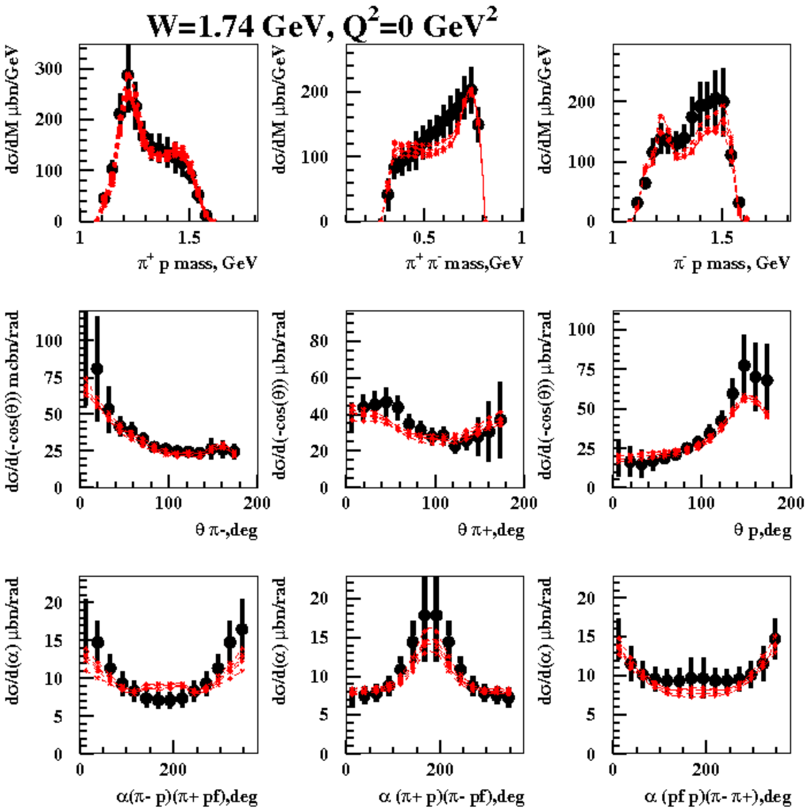
new $3/2^+$(1720) state and consistent with PDG 02' $N\pi\pi$ hadronic decays of N(1720)$3/2^+$:

	Γ_{tot}, MeV	BF($\pi\Delta$) %	BF(ρp) %
$3/2^+$(1720) candidate	88±17	41±13	17±10.
N1720)$3/2^+$ conventional	161±31	<20	60-100



Resonance Photocouplings from the Preliminary $\pi^+\pi^-p$ Photoproduction Cross Sections

Fit of the CLAS data within the framework of the JM15:

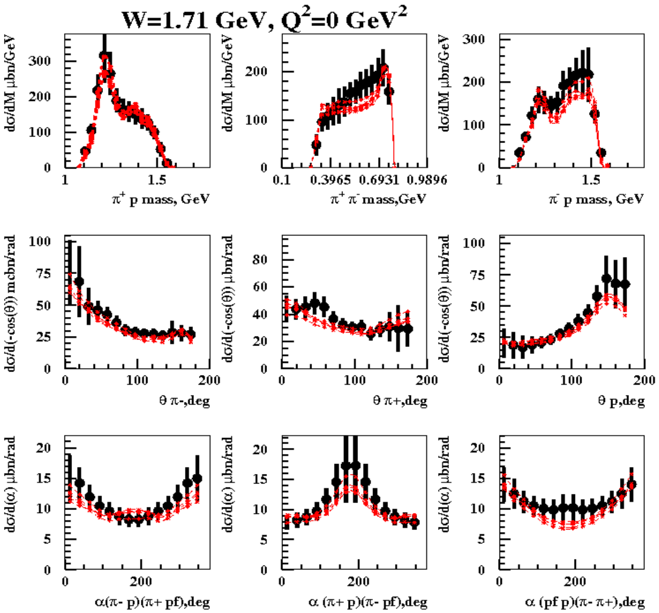


Resonance	$A_{1/2}$, $GeV^{-1/2}$ *1000, JM15/RPP12	$A_{3/2}$, $GeV^{-1/2}$ *1000 JM15/RPP12
$N(1650)1/2^-$	63±6 53±16	
$N(1680)5/2^+$	-29±3 -15±6	133±14 133±12
$N(1700)3/2^-$	-5±4 -18±13	30±22 -2±24
$N'(1720)3/2^+$	40±3 N/A	-43±8 N/A
$N(1720)3/2^+$	89±16 97±3 (*)	-35±13 -39±3(*)
$\Delta(1600)3/2^+$	-26±10 -23±20	-19±9 -9±21
$\Delta(1620)1/2^-$	33±4 27±11	
$\Delta(1700)3/2^-$	97±19 104±15	84±11 85±22
$\Delta(1905)5/2^+$	25±4 26±11	-57±10 -45±20
$\Delta(1950)7/2^+$	-68±16 -76±12	-123±20 -97±10

(*)M. Dugger et al., Phys. Rev. C76, 025211 (2007).

Consistent results on photocouplings of resonances with masses above 1.6 GeV from analyses of $N\pi$ and $\pi^+\pi^-p$ channels demonstrate reliable extraction of these fundamental quantities.

Further Evidence for the Existence of the New State N'(1720)3/2$^+$ from Combined $\pi^+\pi^-p$ Analyses in both Photo- and Electroproduction



Almost the same quality of the photoproduction data fit at 1.66 GeV <W<1.76 GeV and Q^2=0, 0,65, 0.95, 1.30 GeV^2 was achieved with and without N'(1720)3/2$^+$ new states

N* hadronic decays from the data fit that incorporates the new N'(1720)3/2$^+$ state

Resonance	BF($\pi\Delta$), %	BF(ρp), %
N'(1720)3/2$^+$ electroproduction photoproduction	 47-64 46-62	 3-10 4-13
N(1720)3/2$^+$ electroproduction photoproduction	 39-55 38-53	 23-49 31-46
Δ(1700)3/2$^-$ electroproduction photoproduction	 77-95 78-93	 3-5 3-6

N(1720)3/2$^+$ hadronic decays from the CLAS data fit with conventional resonances only

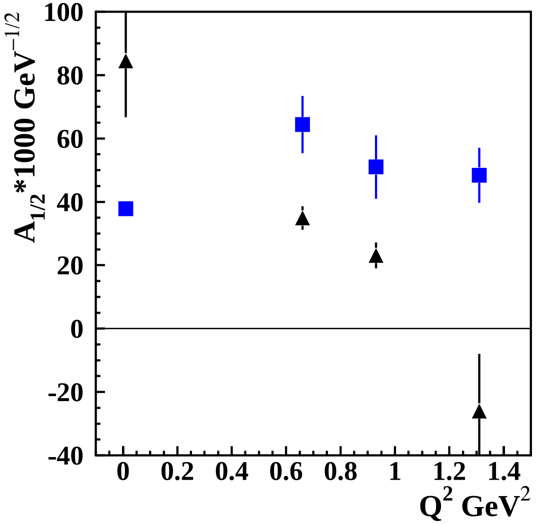
	BF($\pi\Delta$), %	BF(ρp), %
electroproduction	64-100	<5
photoproduction	14-60	19-69

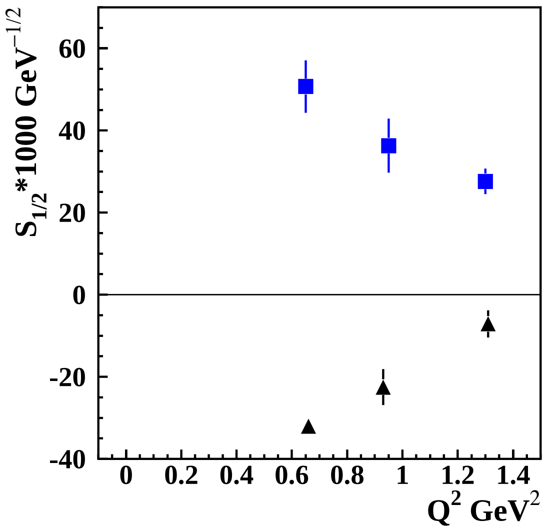
The contradictory BF values for N(1720)3/2$^+$ decays to the $\pi\Delta$ and ρp final states deduced from photo- and electroproduction data make it impossible to describe the data with conventional states only.

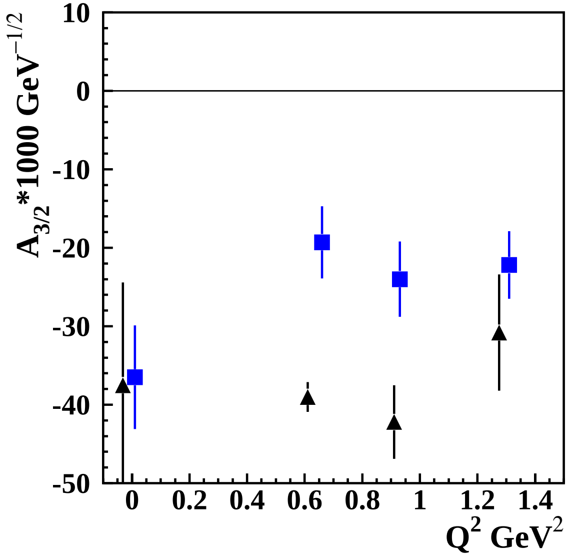
Successful description of $\pi^+\pi^-p$ photo- and electroproduction data achieved by implementing new N'(1720)3/2$^+$ state with Q^2-independent hadronic decay widths of all resonances contributing at W~1.7 GeV <u>provides strong evidence for the existence of new N'(1720)3/2$^+$ state.</u>

The Parameters of N’(1720)3/2$^+$ New State from the CLAS Data Fit

The photo-/electrocouplings of N’(1720)3/2$^+$ and conventional N(1720)3/2$^+$ states:







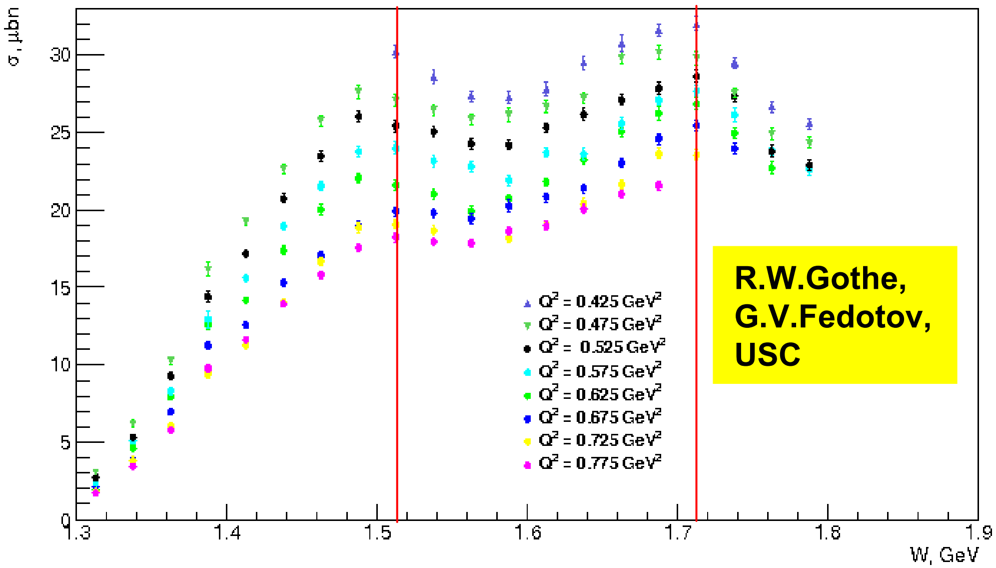
N’(1720)3/2$^+$

N(1720)3/2$^+$

Resonance	Mass, GeV	Total width, MeV
N’(1720)3/2$^+$	1.715-1.735	120±6
N (1720)3/2$^+$	1.743-1.753	112±8

N’(1720)3/2$^+$ is the only candidate state for which the results on Q^2-evolution of transition electrocouplings have become available offering the insight to the structure of the new baryon state.

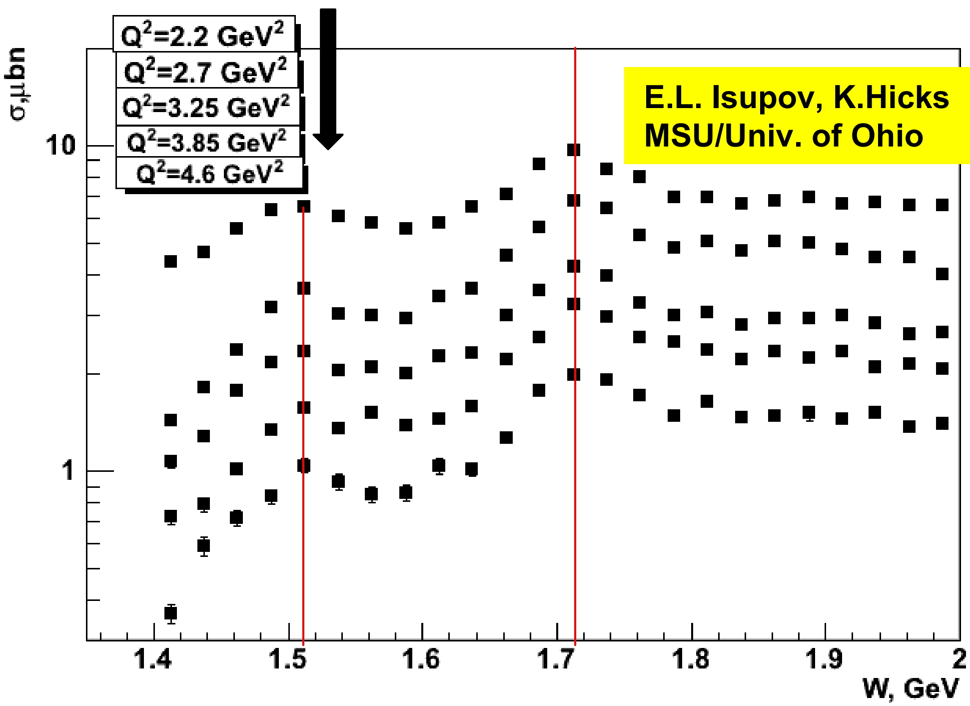
Extension of the CLAS $\pi^+\pi^-p$ Electroproduction Data



<u>Fully integrated $\pi^+\pi^-p$ electroproduction cross sections off protons</u>

•Nine 1-fold differential cross sections are available In each bin of W and Q^2 shown in the plots.

•Resonance structures are clearly seen at W ~1.5 GeV and ~1.7 GeV at 0.4< Q^2< 5.0 GeV^2 (red lines) .



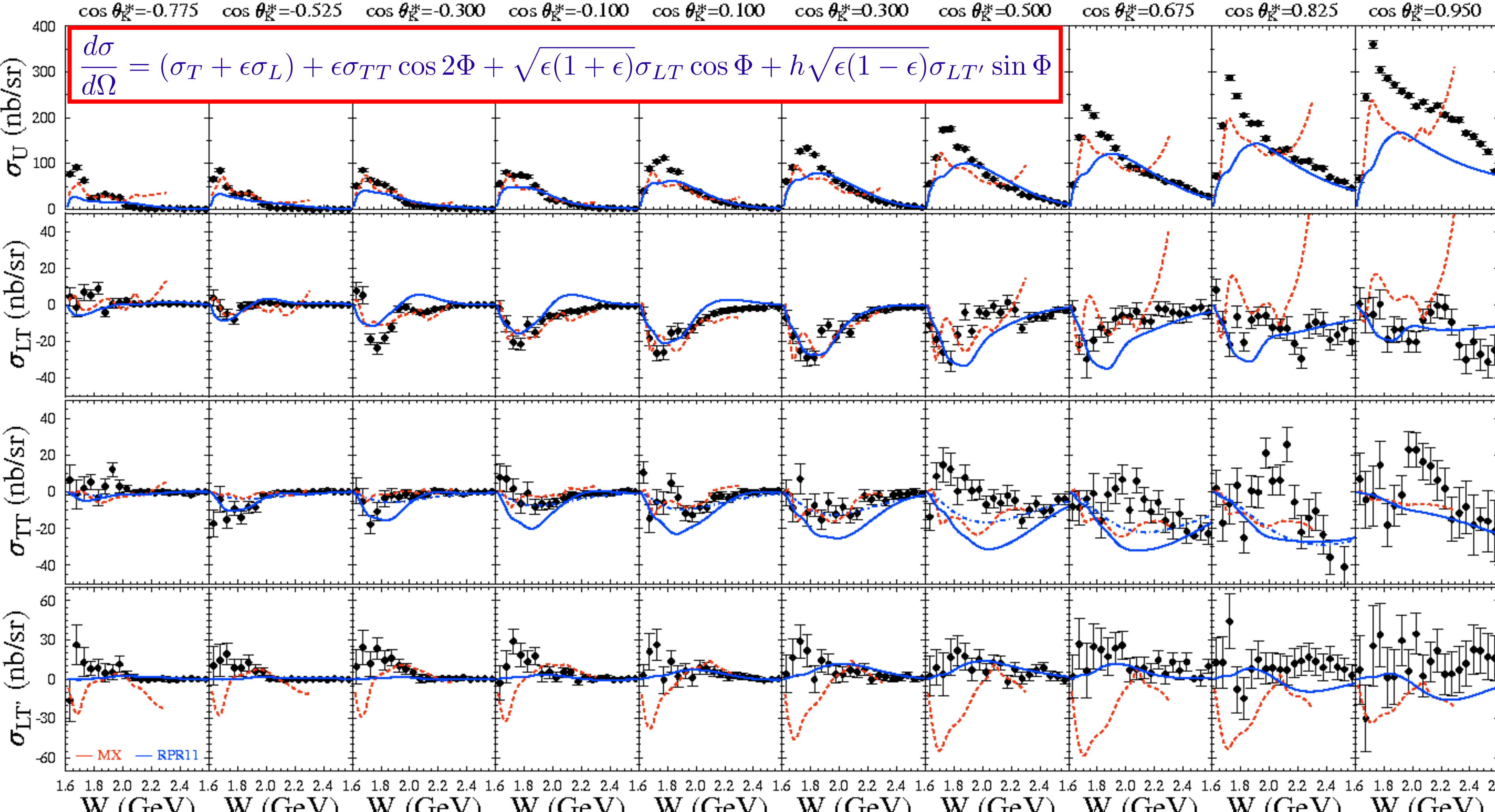
<u>Analysis objectives:</u>

•Extraction of $\gamma_v NN^*$ electrocouplings and $\pi\Delta$, ρp decay widths for most N*s in mass range up to 2.0 GeV and 0.4< Q^2< 5.0 GeV^2 within the framework of JM-model.

•Exploration of the signals from 3/2+(1720) candidate-state (M.Ripani et al., Phys. Rev. Lett 91, 022002 (2003)) with a goal to achieve decisive conclusion on the state existence and structure.

•First results on electrocouplings of high-lying (M_{N^*}>1.6 GeV) orbital nucleon excitations and high-lying parity partners.

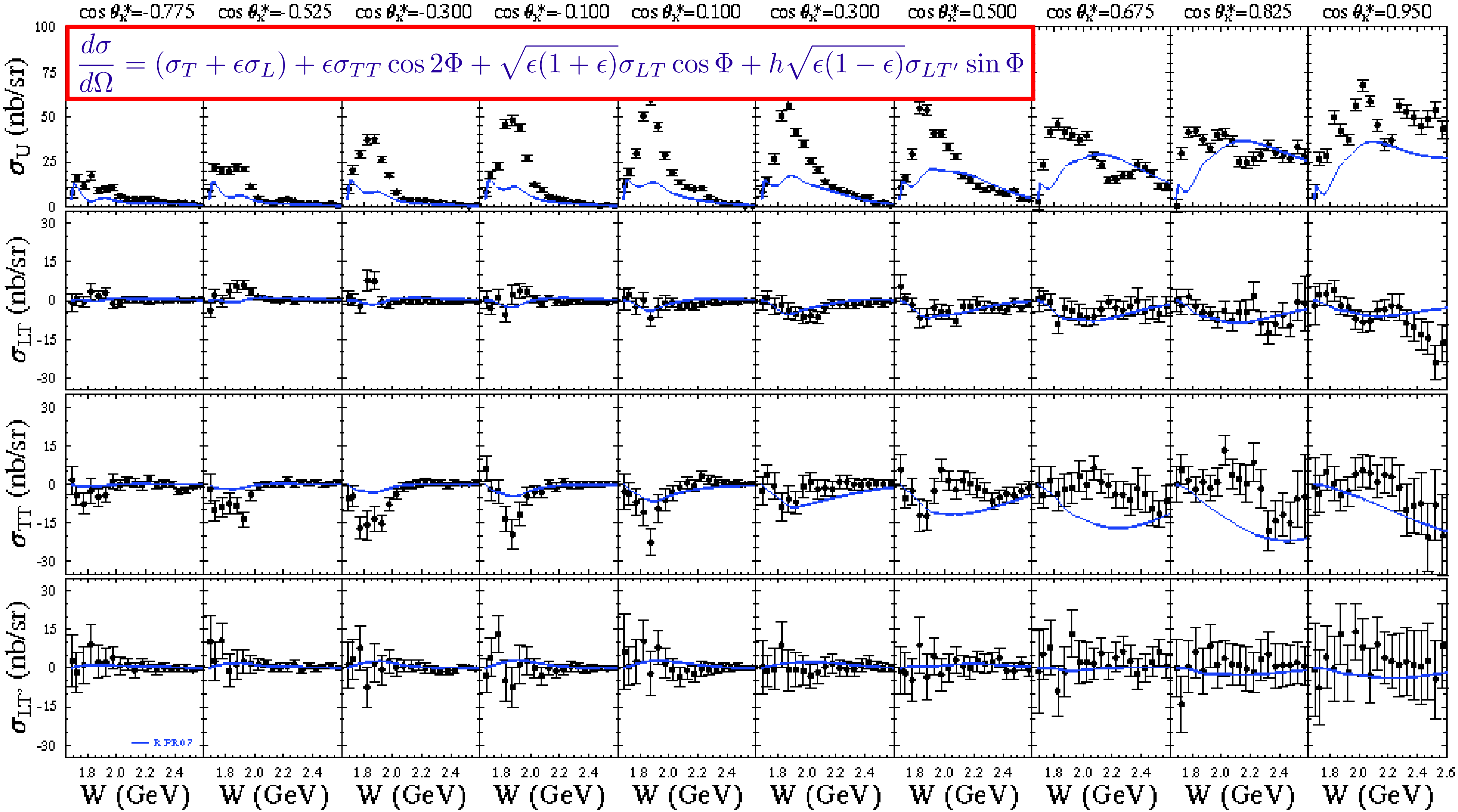
$K^+\Lambda$ Structure Functions



E = 5.5 GeV, W: thr – 2.6 GeV, Q^2 = 1.80, 2.60, 3.45 GeV^2 *[Carman et al., PRC 87, 025204 (2013)]*

$K^+\Sigma^0$ Structure Functions

$$\frac{d\sigma}{d\Omega} = (\sigma_T + \epsilon\sigma_L) + \epsilon\sigma_{TT}\cos 2\Phi + \sqrt{\epsilon(1+\epsilon)}\sigma_{LT}\cos\Phi + h\sqrt{\epsilon(1-\epsilon)}\sigma_{LT'}\sin\Phi$$



E = 5.5 GeV, W: thr – 2.6 GeV, Q^2 = 1.80, 2.60, 3.45 GeV^2 *[Carman et al., PRC 87, 025204 (2013)]*

Signals from N* states in the CLAS KY electroproduction data

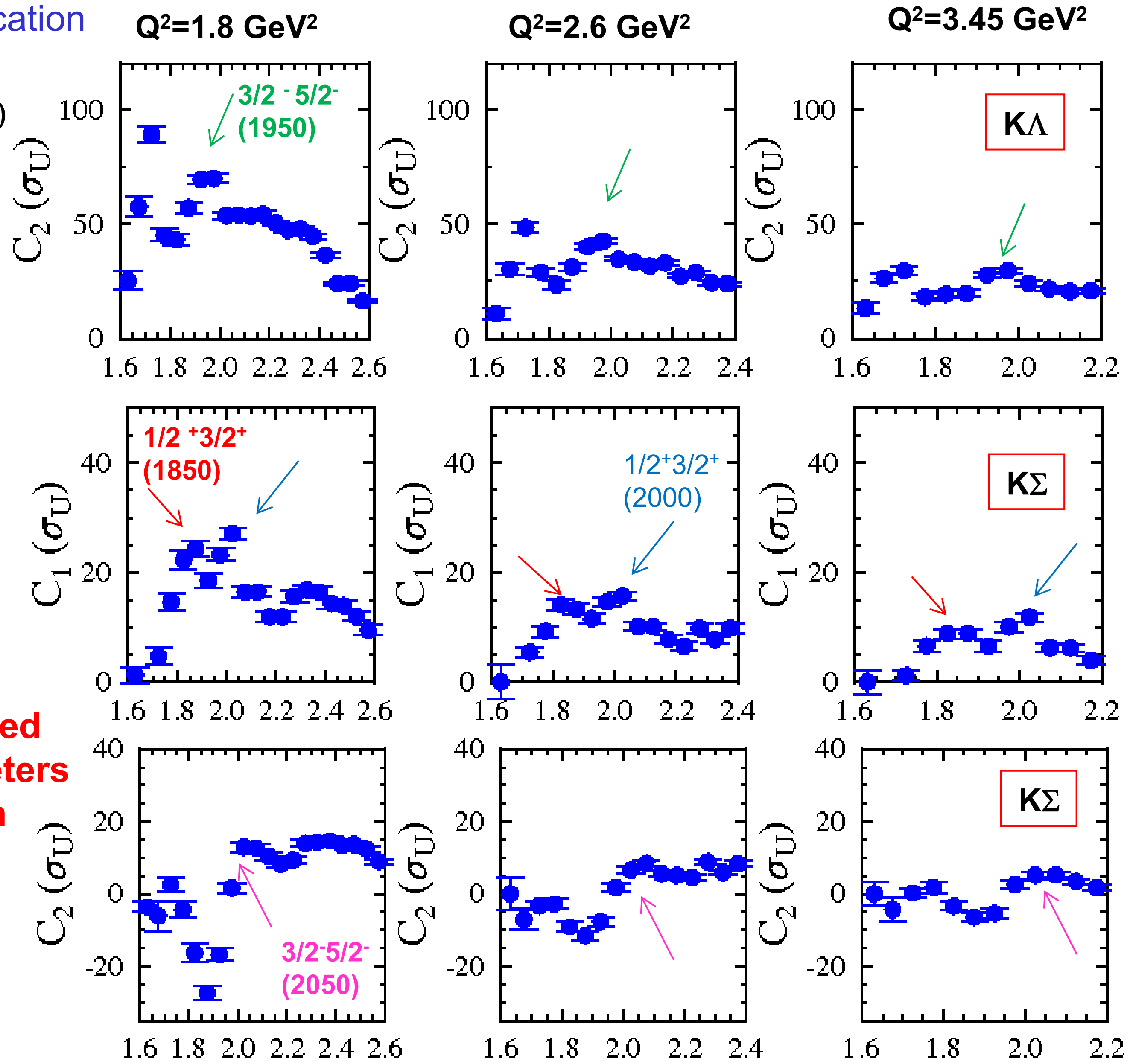
D.Carman, private communication

$$C_l = \int \left\{ \frac{d\sigma}{d\theta_{K_T}} + \varepsilon \frac{d\sigma}{d\theta_{K_L}} \right\} P_l(z)\, d(-z)$$

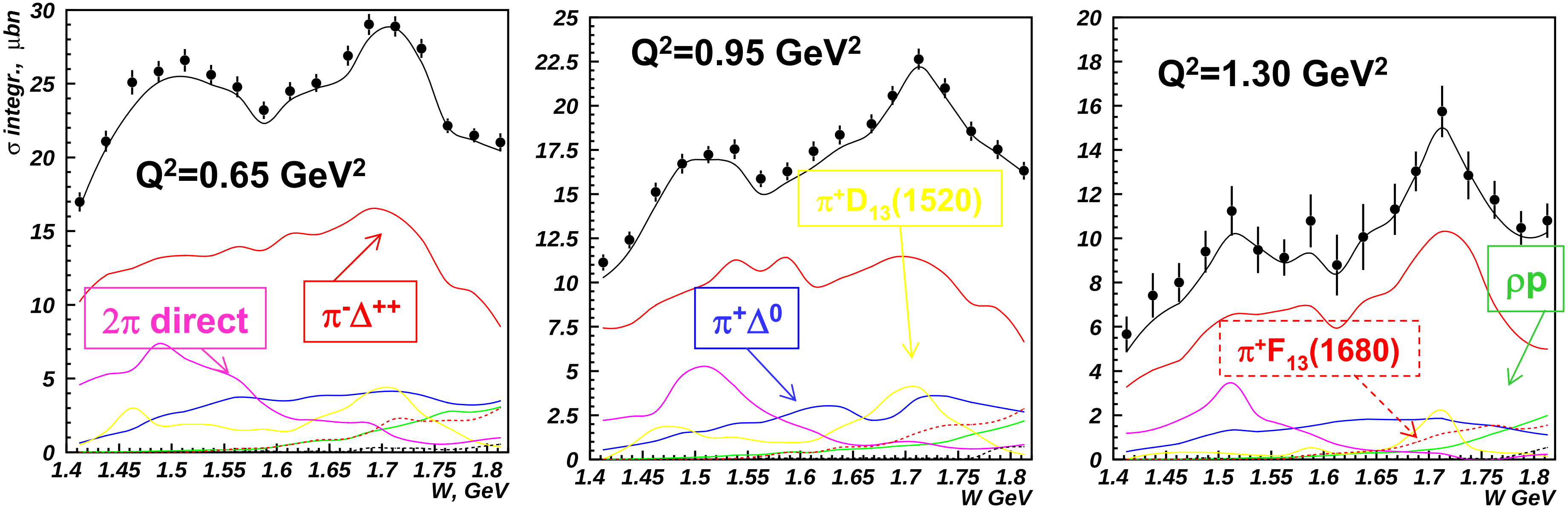
$$z = \cos(\theta_K)$$

the structures in W-dependencies of C_l – moments at the same W-values in all Q^2-bins are consistent with the contributions from resonances of spin-parities listed in the plots

reaction model(s) are needed for extraction of N* parameters from KY electroproduction



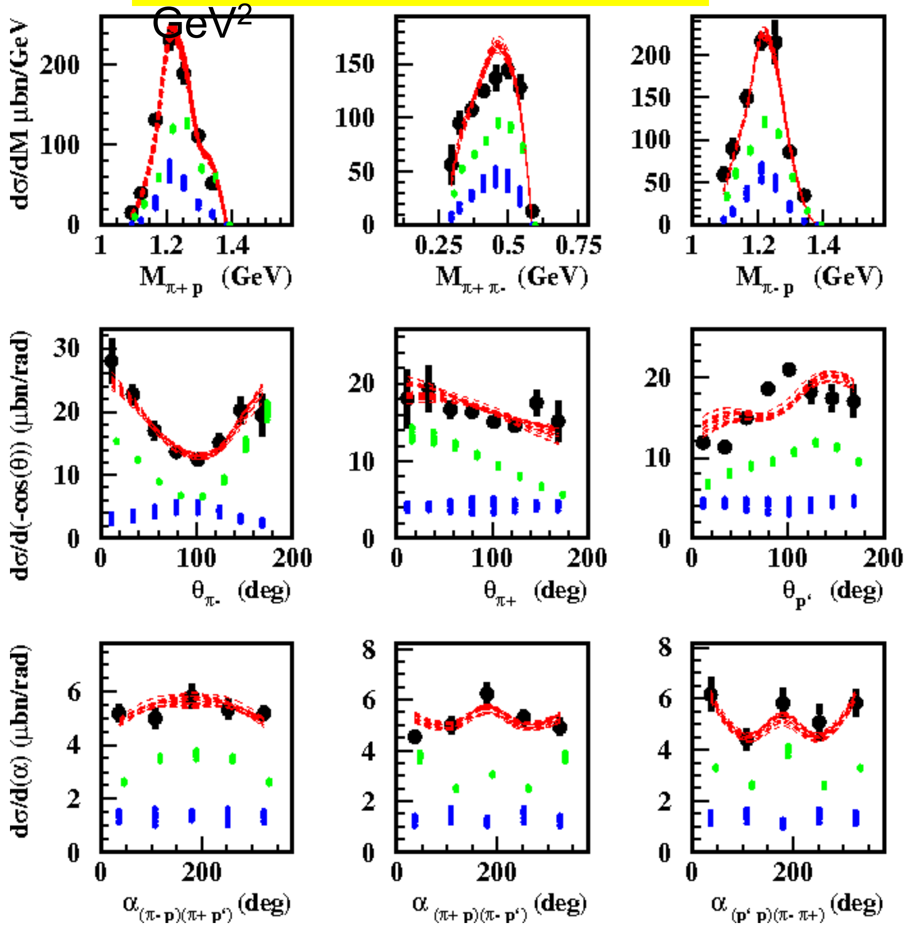
Charting Meson-Baryon Mechanisms of the JM Model



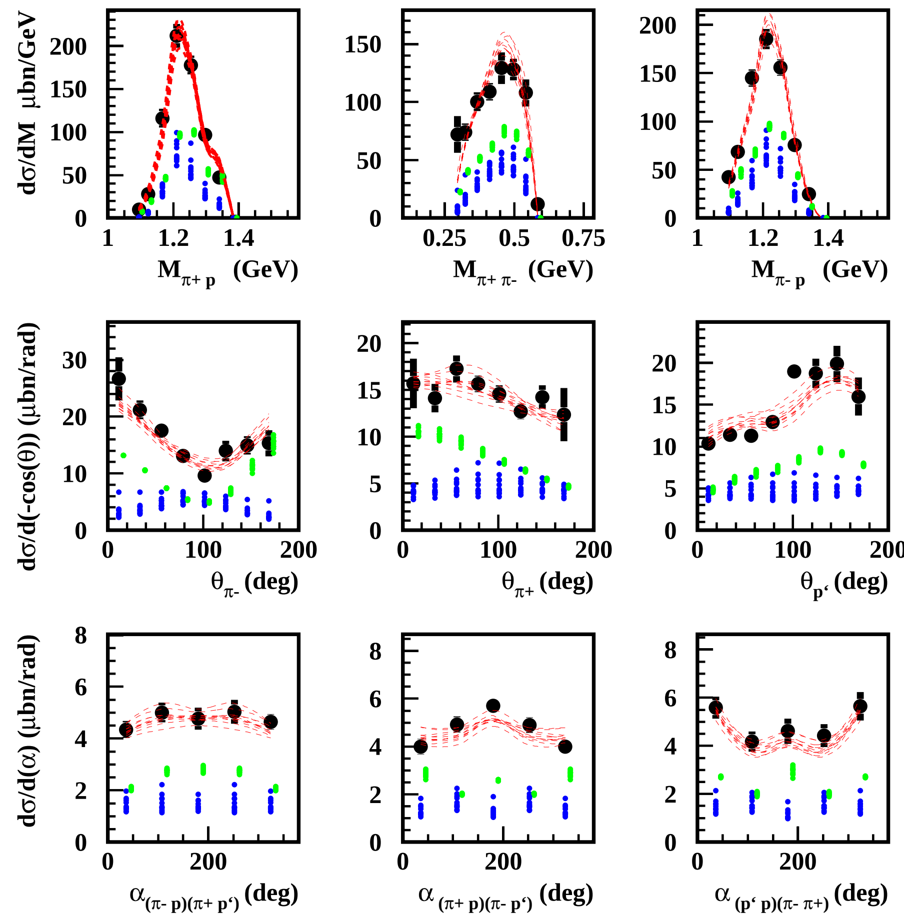
- **$\pi^-\Delta^{++}$ meson-baryon channel accounts for the major part of $\pi^+\pi^-p$ electroproduction cross section. Relative resonant contribution to $\pi^-\Delta^{++}$ channel increases with Q^2.**
- **2π direct production decreases substantially at W from 1.5 to 1.7 GeV offering an indication for sizable final hadronic interactions between the $\pi^+\pi^-p$ final state and others open meson-baryon channels.**
- **$\pi\Delta$, ρp-amplitudes decomposed over PW's of angular momenta J can be provided from the data fit.**
- **The request for reaction theory: guidance for the development of analytical continuation of $\pi\Delta$, ρp-amplitudes allowing us to extract resonance electrocouplings from residues at the resonance pole positions.**

Resonant /Non-Resonant Contributions from the Fit of $\pi^+\pi^-p$ Electroproduction Cross Sections within the JM Model

W=1.51 GeV, Q^2=0.38 GeV^2



W=1.51 GeV, Q^2=0.43 GeV^2



Reliable isolation of the resonant cross sections is achieved

full cross sections within the JM model

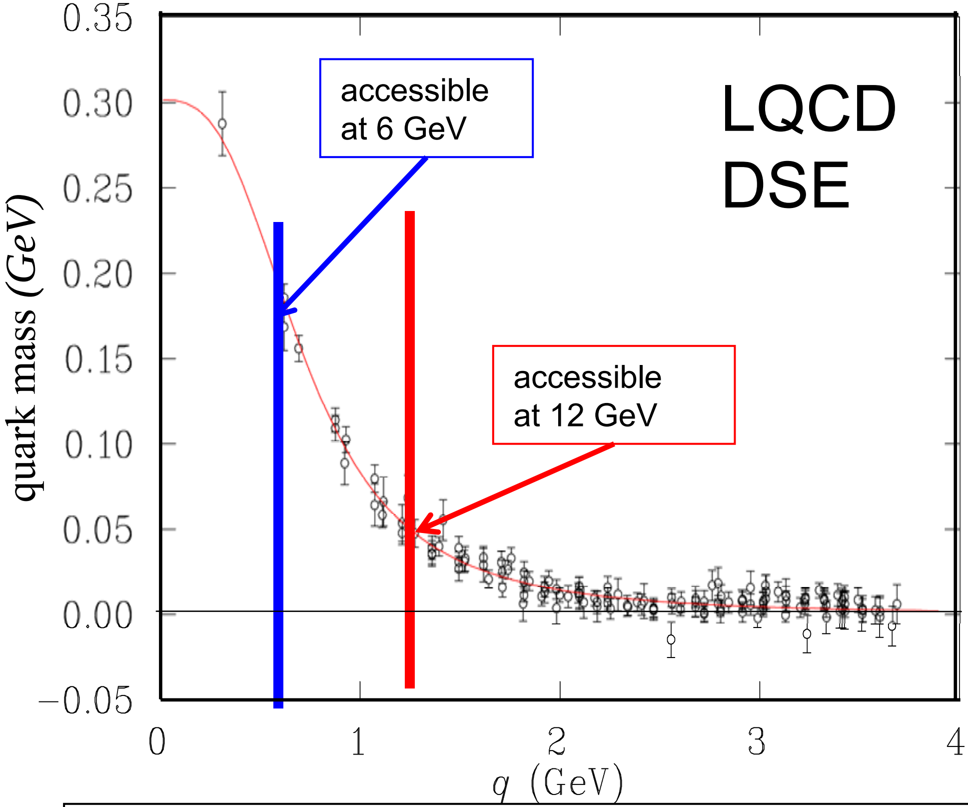
resonant part

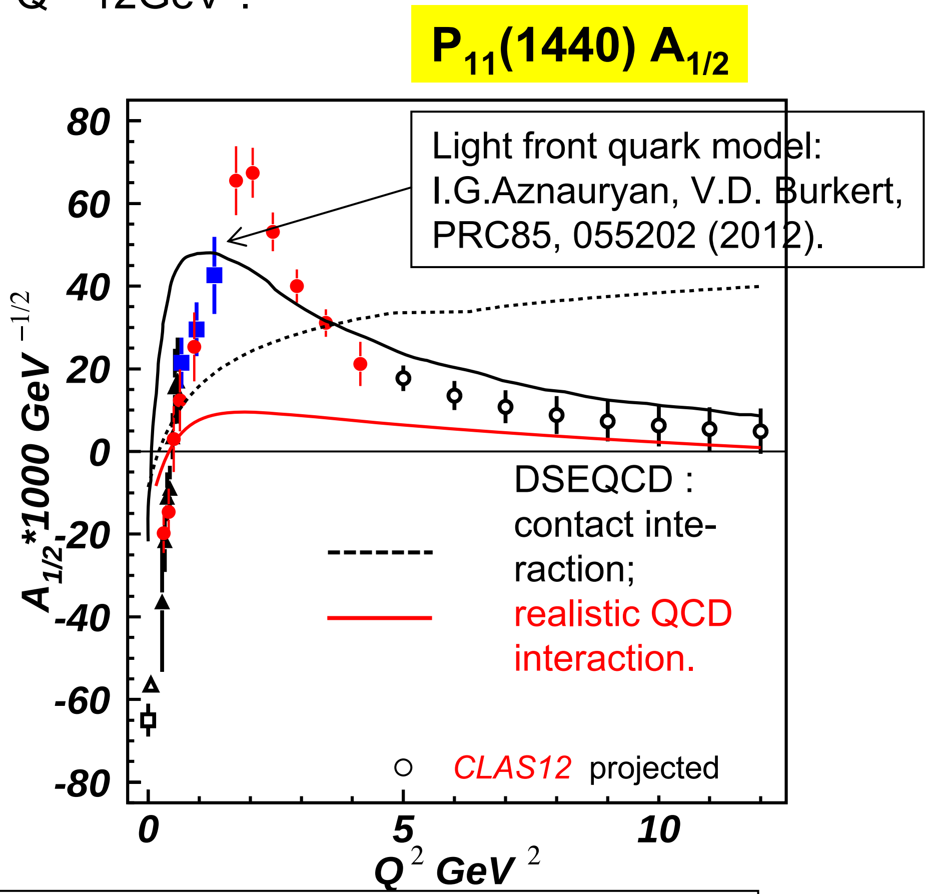
non-resonant part

Resonance Transitions with the CLAS12

Resonance electrocouplings in regime of quark core dominance can be related to the running quark masses and their dynamical structure.

12 GeV experiment E12-09-003 will extend access to electrocouplings for all prominent N* states in the range up to Q^2=12GeV^2.

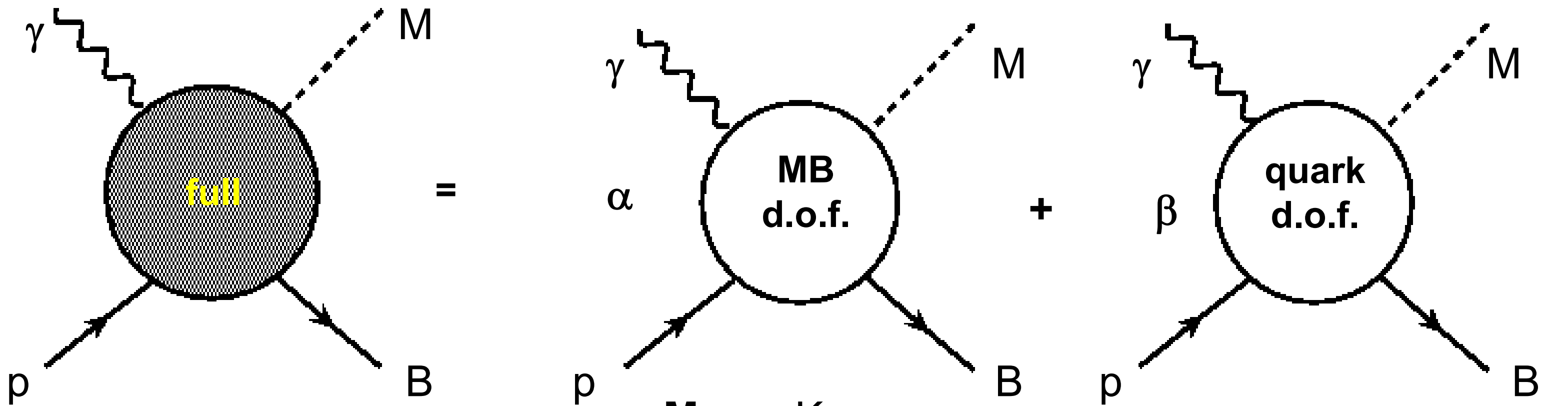




Probe the transition from confinement to pQCD regimes, allowing us to explore how confinement in baryons emerge from QCD and how >98 % of baryon masses are generated non-perturbatively via dynamical chiral symmetry breaking.

Development of the Reaction models with Explicit Implementation of Quark Degrees of Freedom for Extraction of $\gamma_v NN^*$ Electrocouplings at Q^2>5.0 GeV^2

- **Modeling of the amplitudes other than photon-proton s-channel resonances for the exclusive $N\pi$, KY, $\pi\Delta$, and ρp electroproduction at Q^2 up to 12 GeV^2 from minimal accessible W<2.0 GeV to 3.0 GeV. The models should account for:**
  a) hard processes in terms of diagrams with factorized explicit quark degrees of freedom;
  b) relevant soft contributions in terms of meson-baryon degrees of freedom.



M = π, K, ρ
B = N/Δ, Y, p
$\alpha + \beta = 1$

- **Adjustment of the reaction model parameters to all measured with the CLAS observables at Q^2>3.0 GeV^2**

See the talk by: P. Kroll, Thursday, October 15, 11.10 am.

The most urgent task for theory support of the upcoming experiments on the N* structure studies with CLAS12!

The N* Structure at Low Photon Virtualities with CLAS12

Use of the CLAS12 forward tagger will make it possible to obtain the data on $N\pi$, KY, $N\pi\pi$ electroproduction at 0.05 GeV^2 < Q^2 < 1.0 GeV^2 of the best statistical and systematical accuracy ever achieved.

An excellent opportunity to extend the approaches for amplitude extraction from the photoproduction data to electroproduction at small Q^2 and to determine N* parameters under minimal model assumptions:

See the talk by: A. Sarantsev, Tuesday, October 13, 11.50 am.
A. D'Angelo, Friday, October 16, 9.20 am.

New opportunities from the N* structure studies at low Q^2:

- **Check evidence for new N* states from exclusive photoproduction data in analyses of exclusive photo-/electroproduction data combined examining possibility to fit the data with Q^2-independent N* hadronic parameters.**

- **Explore how $S_{1/2}$ electrocouplings are approaching the photon point at Q^2 as low as 0.05 GeV^2.**

- **The studies of N* meson-baryon dressing in details.**

- **Opportunities to probe di-quark correlations in N* states of different quantum numbers.**