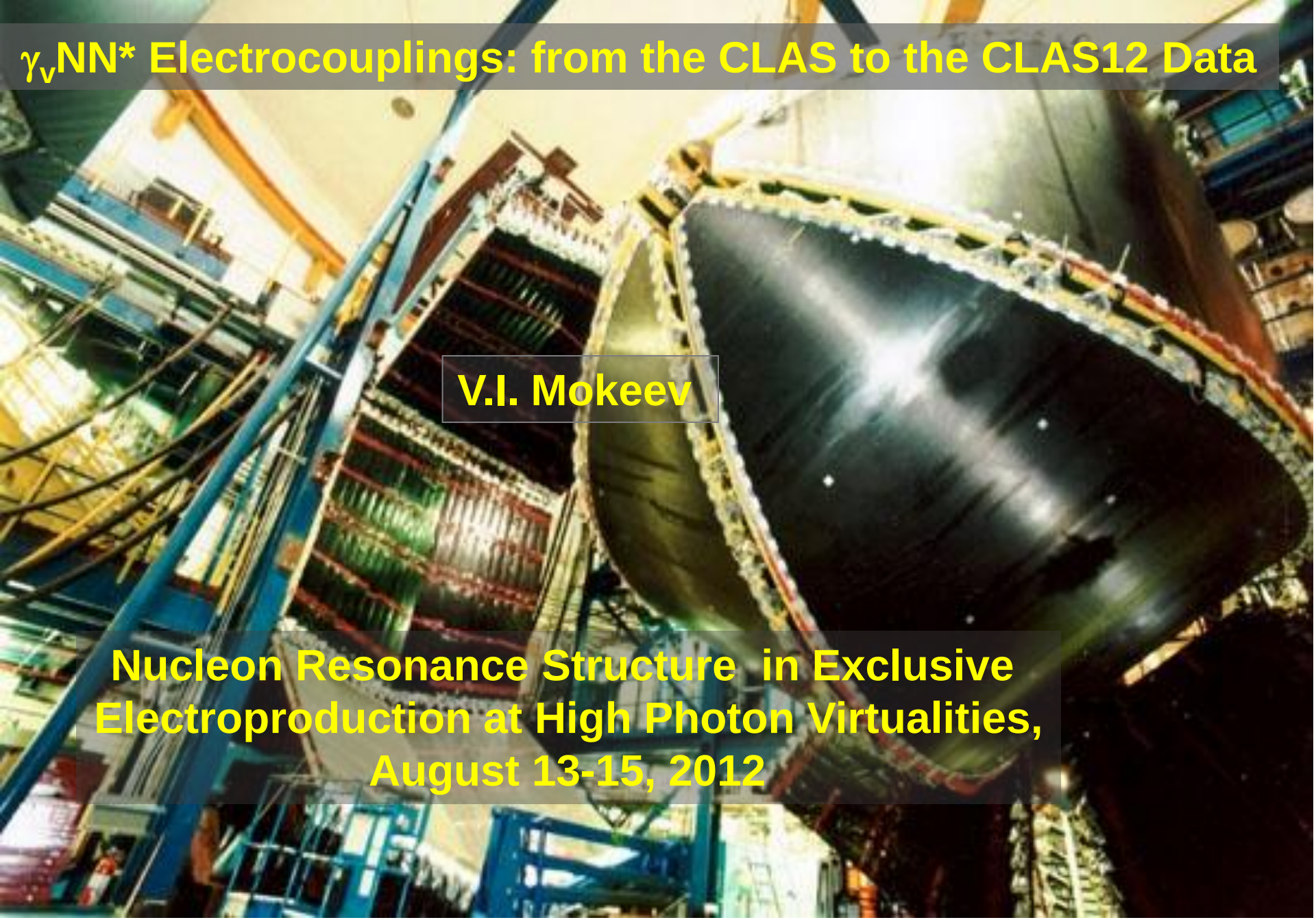
γ_vNN* Electrocouplings: from the CLAS to the CLAS12 Data



V.I. Mokeev

Nucleon Resonance Structure in Exclusive Electroproduction at High Photon Virtualities, August 13-15, 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.

CLAS12 will be a unique worldwide facility for exploring strong interaction in the non-perturbative regime.

The studies of nucleon resonance (N*) structure: motivation and objectives

Our experimental program seeks to determine

γ_vNN* transition helicity amplitudes (electrocouplings) at photon virtualities $0.2< Q^2<6.0$ GeV^2 with CLAS and at $4.0< Q^2<12.0$ GeV^2 with CLAS12 detectors for most of the excited proton states through analyzing major meson electroproduction channels independently and in a global multi-channel analyses.

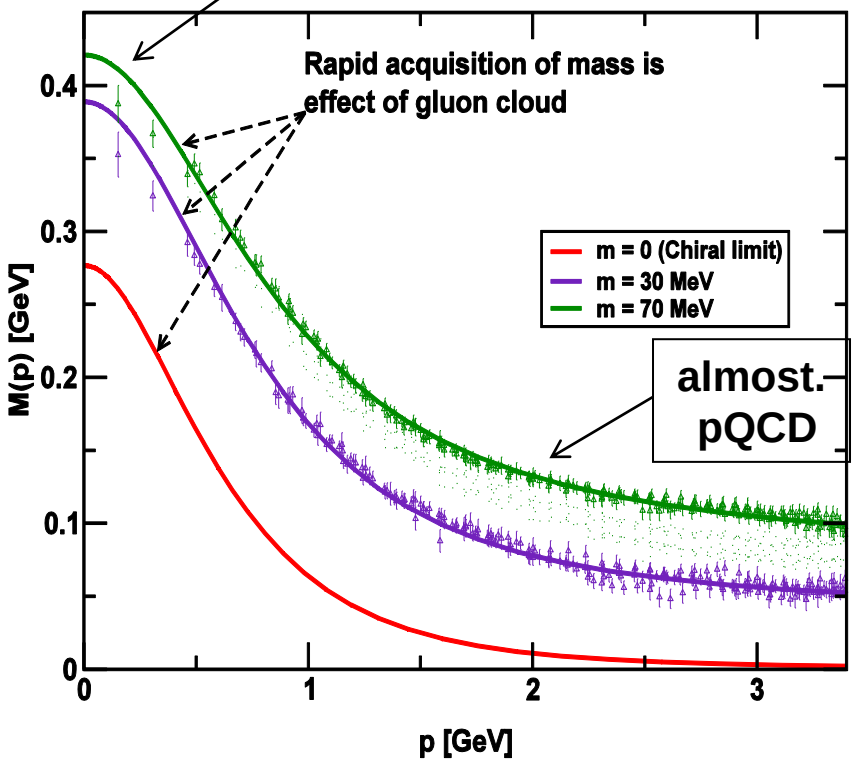
This information is absolutely needed to study the non-perturbative strong interaction which generates N* states as the bound systems of quarks and gluons

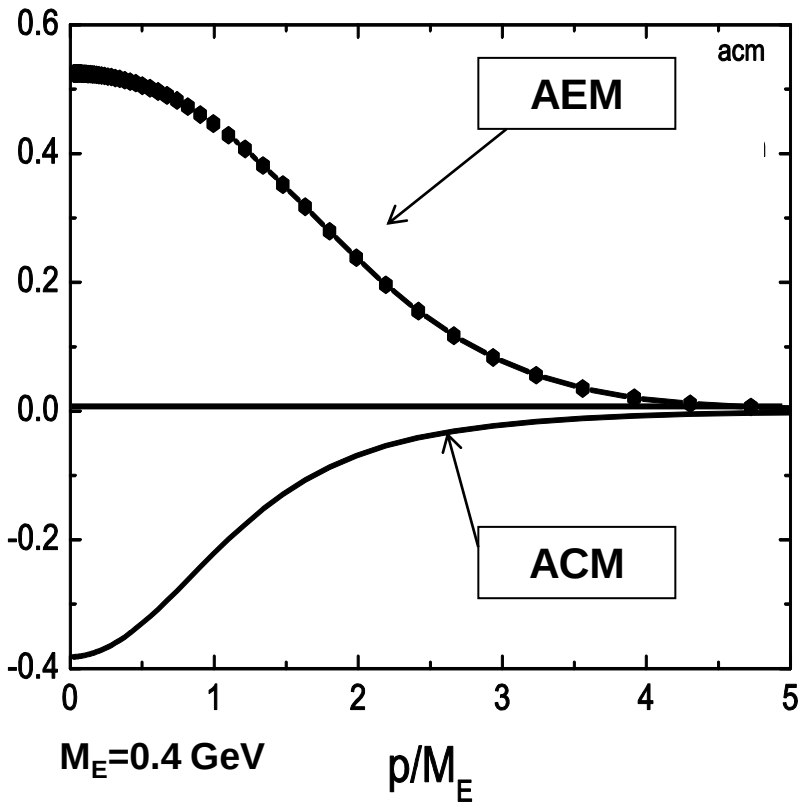
The non-perturbative strong interaction represents the most important part of the Standard Model that we have yet to explore. The non-perturbative strong interaction is far more complex than the electromagnetic and weak interactions; and very different in nature.

Dynamical mass and structure of dressed quarks

strong confinement

L.Chang et al, PRL 106, 072001 (2011)



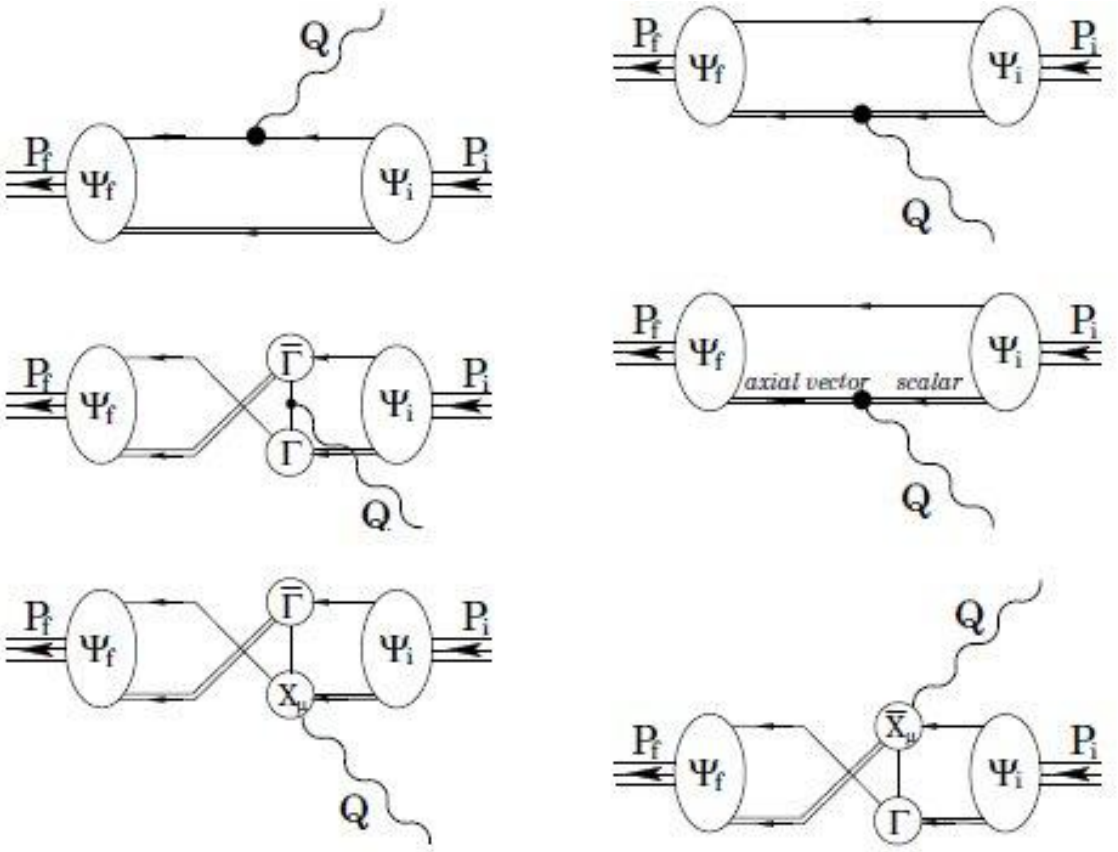


- > 98% of dressed quark and N* masses and their dynamical structure are generated non-pertutbatively through dynamical chiral symmetry breaking (DCSB). The Higgs mechanism accounts for less than 2% of the nucleon & N* mass.
- the data from CLAS/CLAS12 will allow us to explore the nature of the dominant part of hadron mass.
- the momentum dependence of the dressed quark mass reflects the transition from quark/gluon confinement to pQCD .

γ_vNN* electrocouplings as a window to strong interactions in non-perturbative region

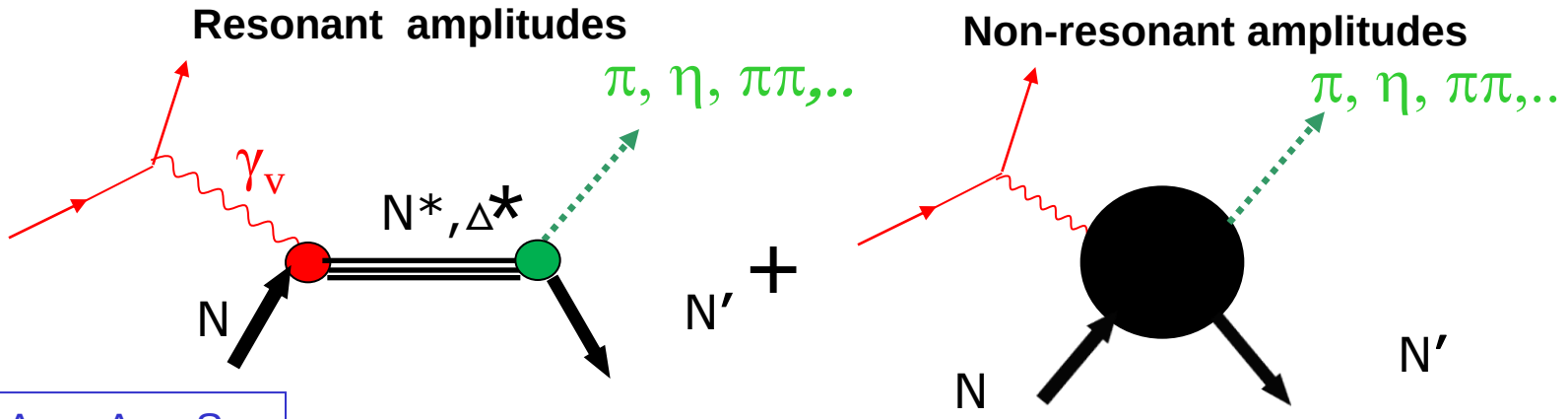
Quark core contribution to γ_vNN* electrocouplings

- quark propagators are sensitive to the quark running mass M(p);
- dressed quark e.m. current is sensitive to the quark anomalous electrpomagnetic moment (AEM);
- quark interaction vertices Γ and X are sensitive to the quark anomalous chrmomagnetic moment (ACM).



Studies of γ_vNN* electrocouplings at different photon virtualities Q^2 provide access to the quark mass function, structure, and qq-interactions, which are responsible for N* formation. Our studies will offer a unique way to explore quark/gluon confinement and DCSB in baryons.

Extraction of γ_vNN* electrocouplings from the data on exclusive meson electroproduction off protons



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

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

- **Separation of resonant/non-resonant contributions within the framework of reaction models; Breit Wigner ansatz for parameterization of resonant amplitudes; fit of γ_vNN* electrocouplings and hadronic parameters to the data.**

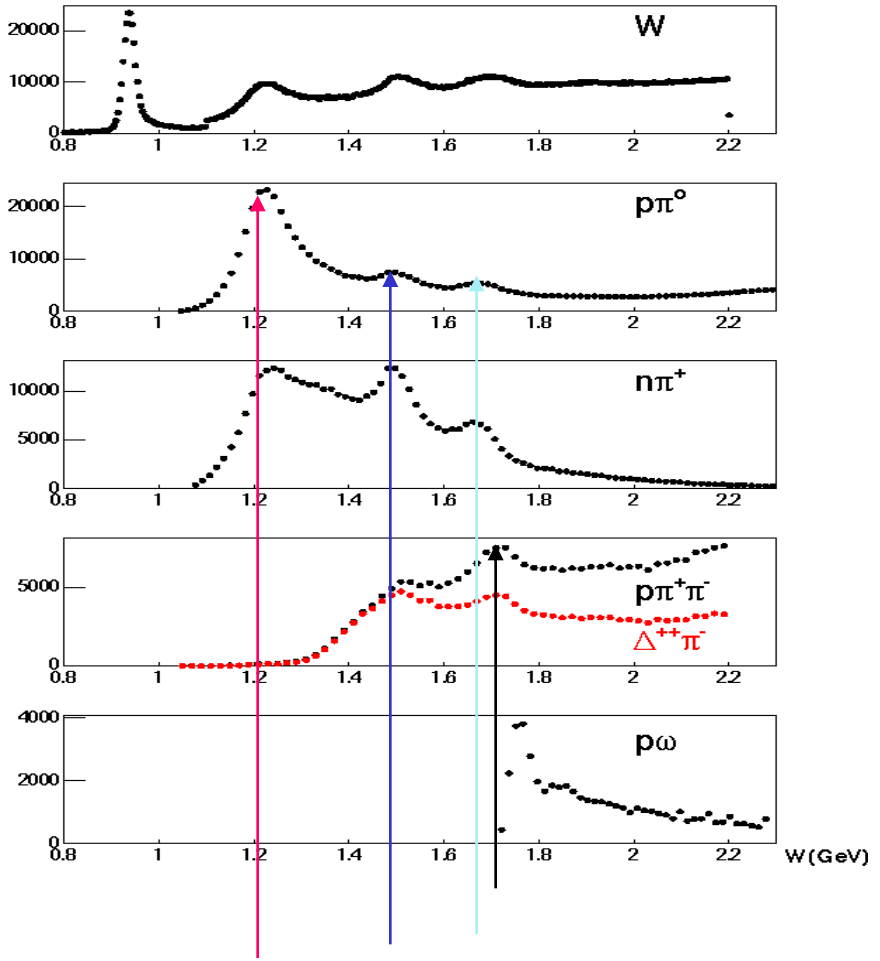
- **Consistent results on γ_vNN* electrocouplings from different meson electroproduction channels demonstrate reliable extraction of N* parameters.**

N* electroexcitation in meson electroproduction off protons

Hadronic decays of prominent N*s for W<1.8 GeV.

State	Branch. Fract. to Nπ.	Branch. Fract. to Nη	Branch.Frac .to Nππ
Δ(1232) P_{33}	0.995		
N(1440) P_{11}	0.55-0.75		0.3-0.4
N(1520) D_{13}	0.55-0.65		0.4-0.5
N(1535) S_{11}	0.48±0.03	0.46±0.02	
Δ(1620) S_{31}	0.20-0.30		0.70-0.80
N(1650) S_{11}	0.60-0.95	0.03-0.11	0.1-0.2
N(1685) F_{15}	0.65-0.70		0.30-0.40
Δ(1700) D_{33}	0.1-0.2		0.8-0.9
N(1720) P_{13}	0.1-0.2		> 0.7

CLAS data on yields of meson electroproduction reactions at $Q^2<4$ GeV^2



Nπ//Nππ channels are sensitive to N*s. They are major contributors to meson exclusive electroproduction in the N* excitation region.

Summary of the CLAS data on single-pion electroproduction off protons

Number of data points >125000, W<1.7 GeV, $0.15<Q^2<6.0$ GeV^2, almost complete coverage of the final state phase space. Extended toward W<3.0 GeV $Q^2<5.$ GeV^2

Observables	Q^2 area, GeV^2	Number of data points
$d\sigma/d\Omega(\pi^0)$	0.16-1.45 3.0-6.0	39830 9000
$d\sigma/d\Omega(\pi^+)$	0.25-0.60 1.7-4.3	25588 30 849
$A_e(\pi^0)$, $A_t(\pi^0)$	0.25-0.65	3981
$A_e(\pi^+)$, $A_t(\pi^+)$	0.40-065 1.7 - 3.5	1730 3 535
$A_{et}(\pi^0)$	0.25-0.61	1521

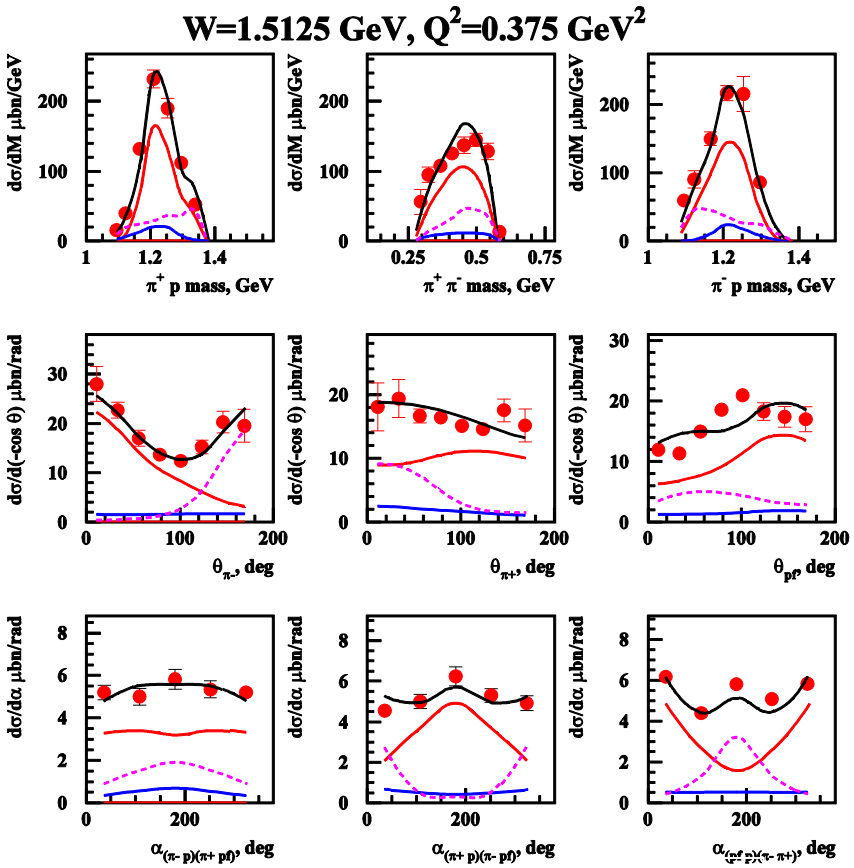
Low Q^2 results:
I. Aznauryan *et al*., PRC 71, 015201 (2005); PRC 72, 045201 (2005).

High Q^2 results on Roper:
I. Aznauryan *et al*., PRC 78, 045209 (2008).

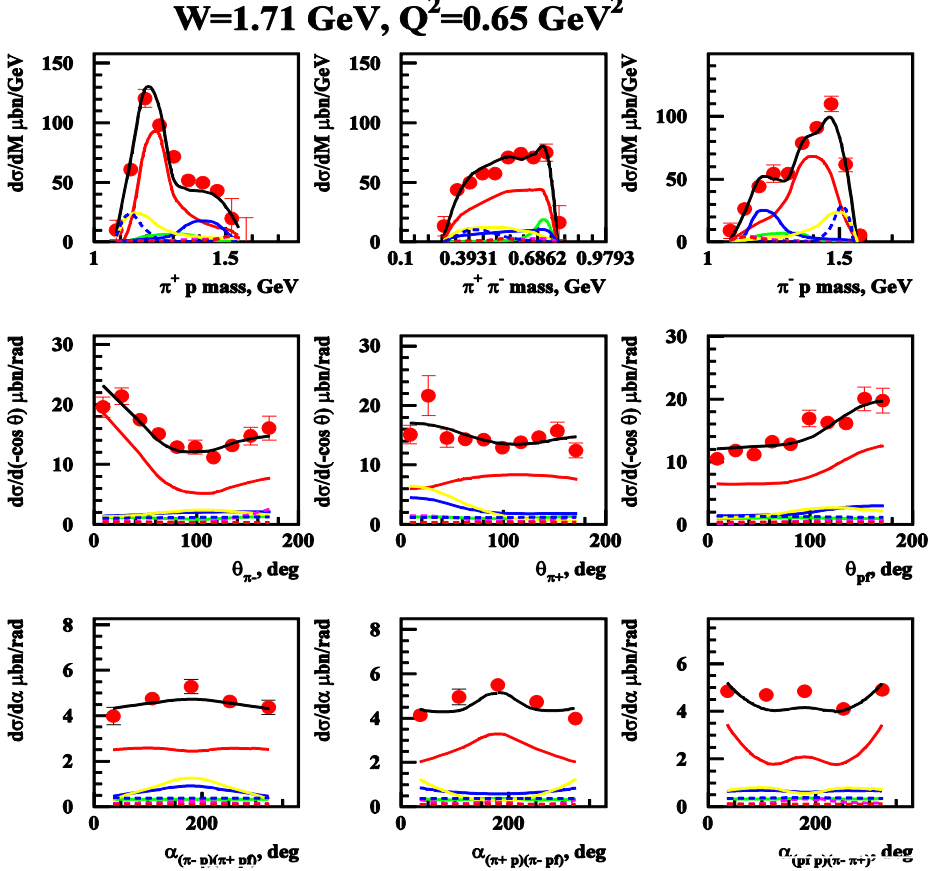
Final analysis:
I.G.Aznauryan, V.D.Burkert et al. (CLAS Collaboration), PRC 80. 055203 (2009).

The CLAS data on $\pi^+\pi^-p$ differential cross sections and their fit within the framework of meson-baryon reaction model JM

G.V.Fedotov et al, PRC 79 (2009), 015204
1.30<W<1.56 GeV; 0.2<Q^2<0.6 GeV^2



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



full JM calc. — $\pi^+\Delta^0$ — ρp — $\pi^+F^0_{15}(1685)$

$\pi^-\Delta^{++}$ — 2π direct — $\pi^+D^0_{13}(1520)$

Summary of the CLAS/Hall-C data on ηp electroproduction off protons

Observables	Coverage over Q^2, GeV^2	Coverage over W, GeV	References
$d\sigma/d\Omega$	2.4, 3.6	1.48-1.62	[1]
$d\sigma/d\Omega$	0.38-2.5	1.50-1.86	[2]
$d\sigma/d\Omega$	0.13-3.3	1.50-2.30	[3]
$d\sigma/d\Omega$	5.7,7.0	1.50-2.30	[4]

1. C.S. Armstrong et al., Phys. Rev D60, 052004 (1999).

2. R. Thompson et al., (CLAS Collaboration), Phys. Rev. Lett. 86, 1702 (2001).

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

4. M.Dalton et al., Phys. Rev. C80, 015205 (2009).

Summary of the CLAS data on KY electroproduction off protons

Observables	Channel	Coverage over Q^2, GeV^2	Coverage over W, GeV	References
$P_{x,y,z}$	$K\Lambda, K\Sigma^0$	0.7-5.4	1.60-2.60	[1]
A_e	$K\Lambda$	0.65-1.0	1.60-2.05	[2]
$d\sigma/d\Omega$	$K\Lambda, K\Sigma^0$	0.5-2.8	1.60-2.40	[3]
$P_{x,y,z}$	$K\Lambda$	0.3-1.5	1.60-2.15	[4]

1. D.S. Carman et al.,(CLAS Collaboration), Phys. Rev. C79, 065205 (2009).
2. R. Nasseripour et al., (CLAS Collaboration), Phys. Rev. C77, 065208 (2008).
3. P. Ambrozewicz et al., (CLAS Collaboration), Phys. Rev. C75, 045203 (2007).
4. D.S. Carman et al., (CLAS Collaboration), Phys. Rev. Lett. 90, 131804 (2003).

More than 85% of meson electroproduction data worldwide were obtained in experiments with the CLAS detector and available in the CLAS Physics Data Base: http://clasweb.jlab.org/physicsdb/

Approaches for extraction of γ_vNN* electrocouplings from the CLAS data on exclusive meson electroproduction channels

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

➢ π^+n and π^0p channels:

Unitary Isobar Model (UIM) and Fixed-t Dispresion Relations (DR)

I.G.Aznauryan, Phys. Rev. C67, 015209 (2003).

I.G.Aznauryan et al., CLAS Coll., Phys Rev. C80, 055203 (2009).

➢ 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)

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

V.I.Mokeev et al., CLAS Coll., arXiv:1205.3948 [nucl-ex], accepted by PRC.

- **Global coupled-channel analyses of the CLAS/world data of πN, γ_vN → πN, ηN,$\pi\pi$N, KΛ, KΣ exclusive channels:**

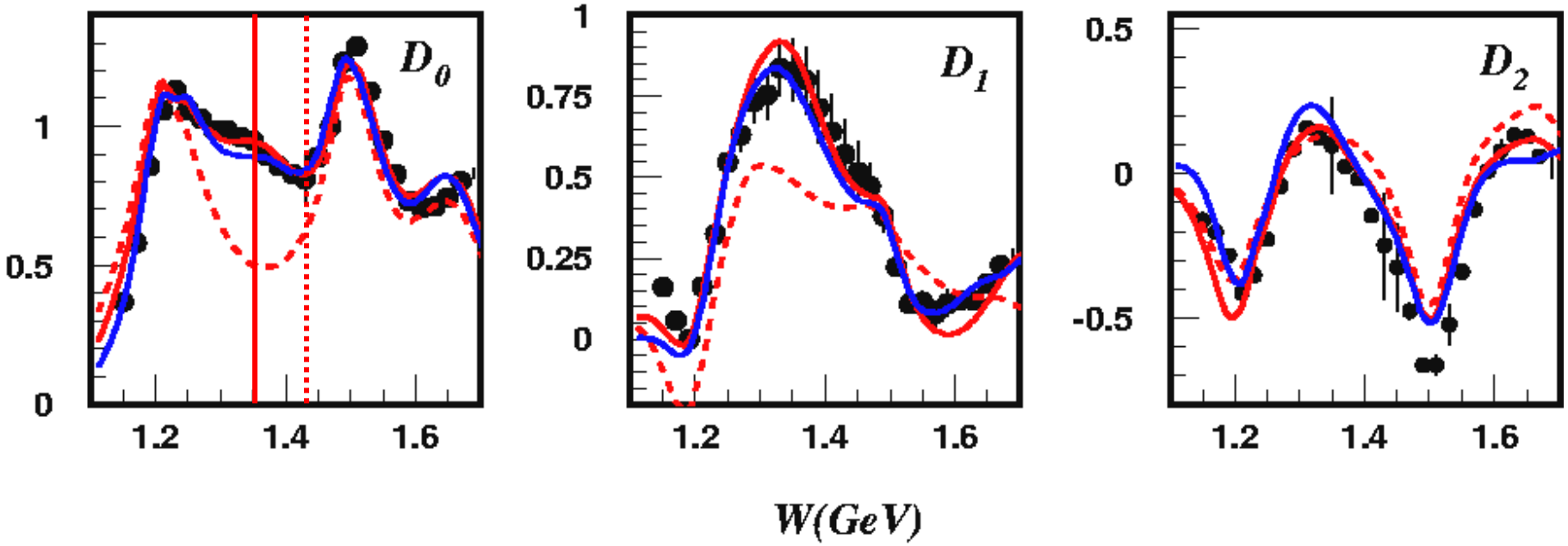
N.Suzuki, T.Sato , and T-S. H.Lee, Phys, Rev. C82, 045206 (2010).

Talk by T.Sato, Tuesday, August 14.

Fit of the Legendre Moments of Unpolarized Structure Functions

K. Park *et al.* (CLAS), Phys. Rev. C77, 015208 (2008)

Q^2=2.05GeV^2



$$\sigma_T + \epsilon\sigma_L = \sum_{l=0}^{n} D_l^{T+L} P_l(\cos\theta_\pi^*)$$

I. Aznauryan —— DR fit

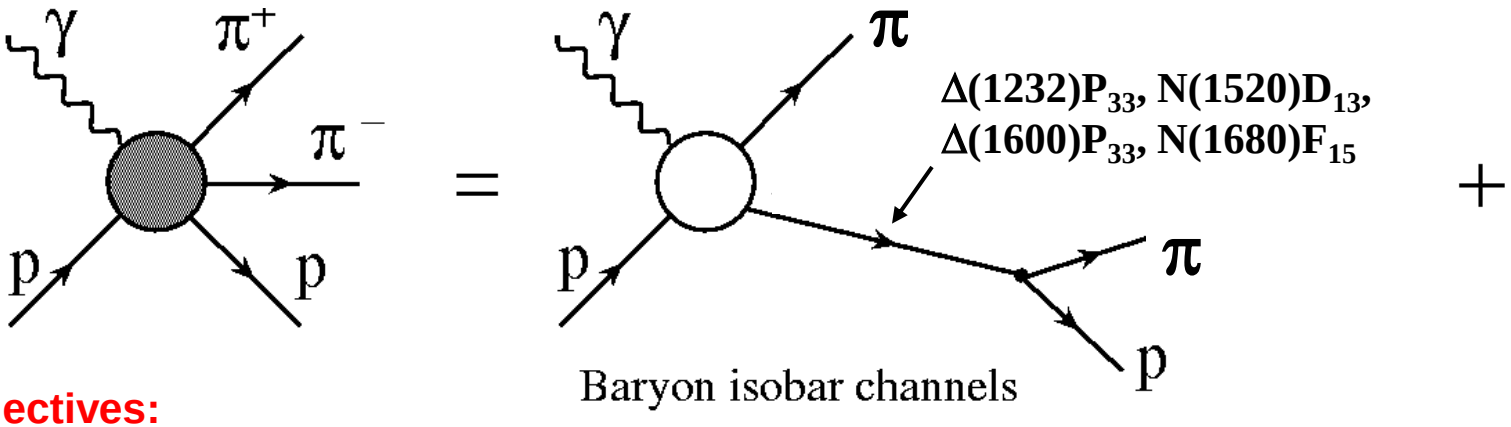
I. Aznauryan - - - DR fit w/o P_{11}

I. Aznauryan —— UIM fit

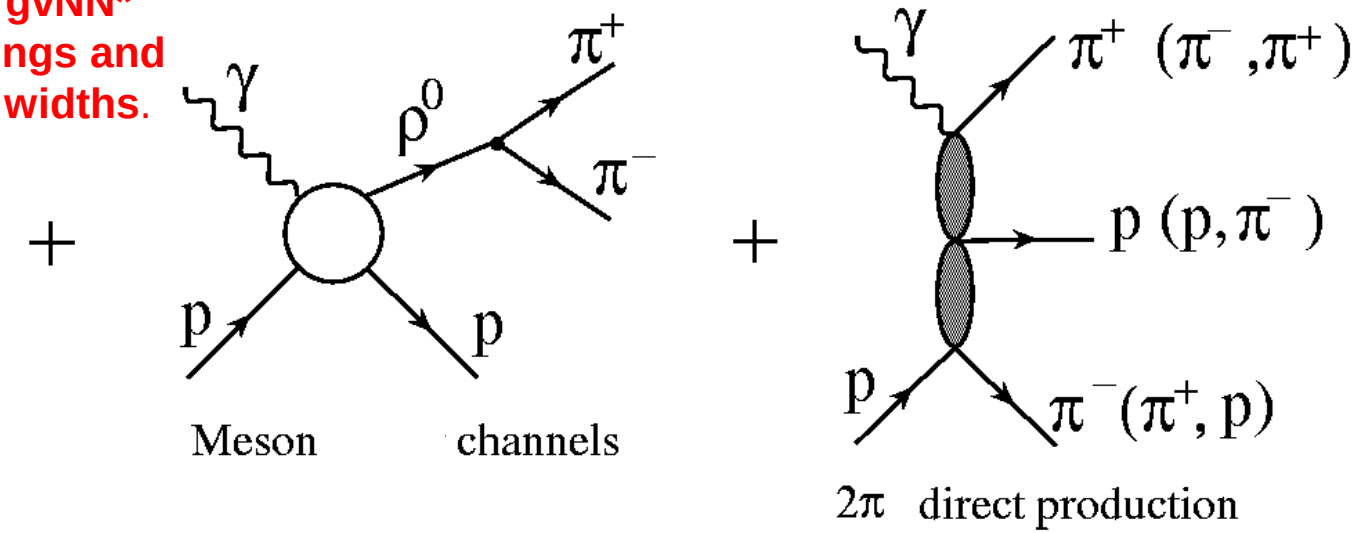
Two conceptually different approaches DR and UIM are consistent. CLAS data provide rigid constraints for checking validity of the approaches.

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

V. I. Mokeev , V.D. Burkert, T.-S.H. Lee *et al*., Phys. Rev. C80, 045212 (2009)



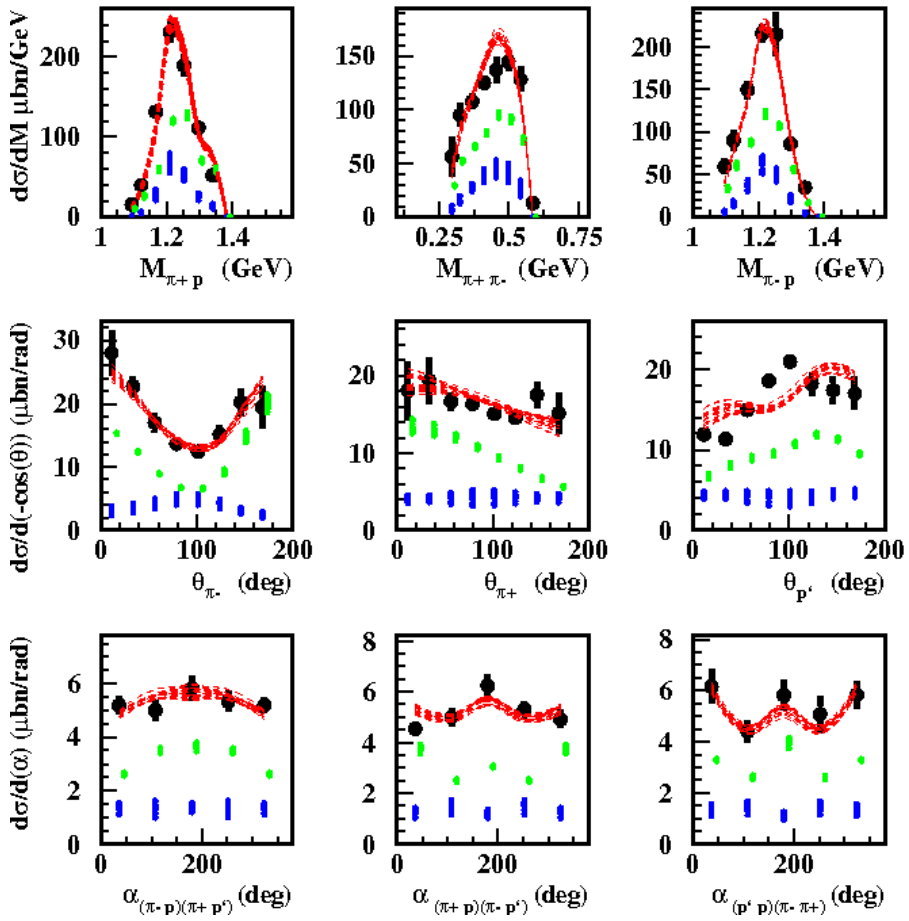
Major objectives: extraction of gvNN* electrocouplings and πΔ, ρp decay widths.



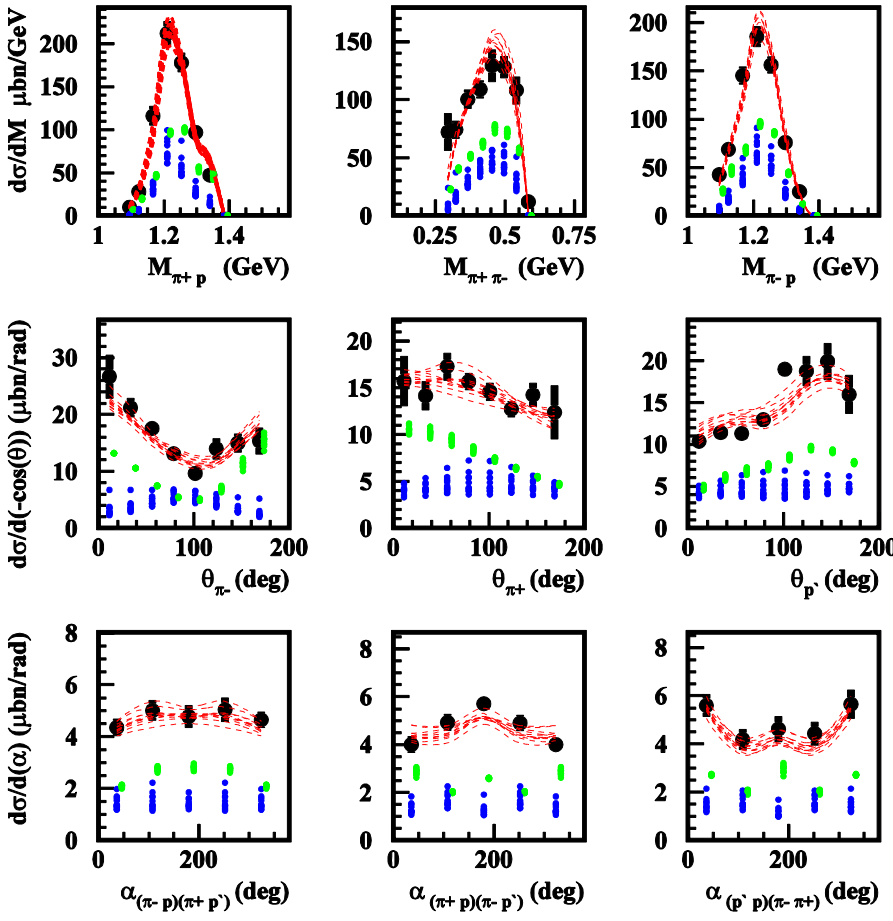
N* contribute to πΔ and ρp channels only. Resonant amplitudes are parametrized within the framework of an updated BW ansatz, which imposes the constraint of unitarity.

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

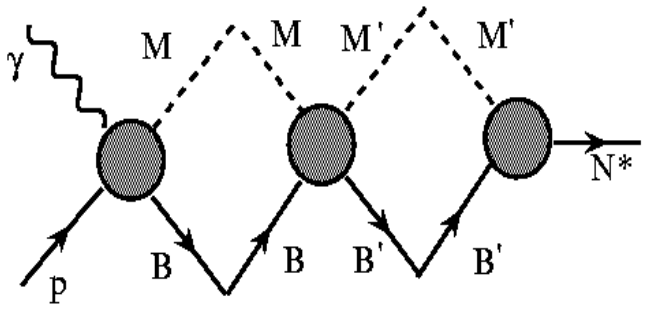
full cross sections within the JM model

resonant part

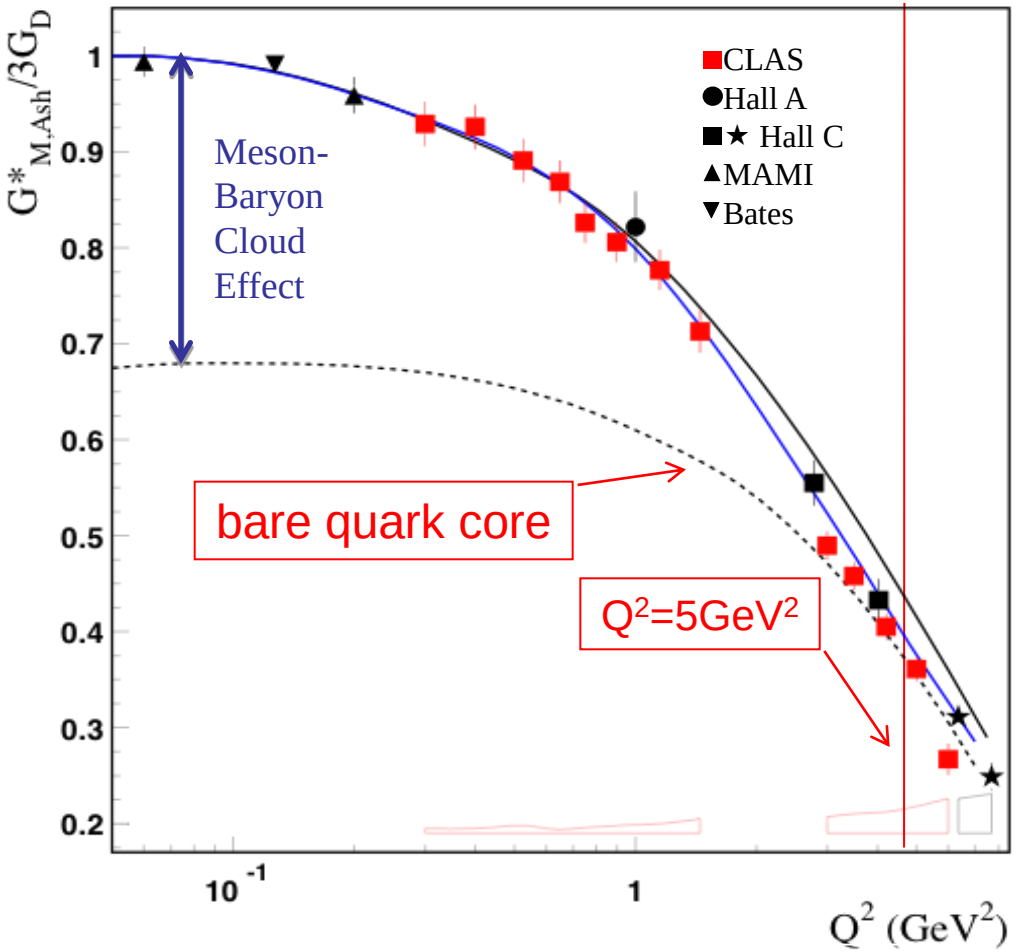
non-resonant part

NΔ Transition Form Factor – $G_{M.}$ Meson-baryon dressing vs Quark core contribution in EBAC-DCC analysis.

- One third of G^*_M at low Q^2 is due to contributions from meson–baryon (MB) dressing:



Within the framework of relativistic QM [B.Julia-Diaz *et al.*, PRC 69, 035212 (2004)], the bare-core contribution is very well described by the three-quark component of wave function



The transition to pQCD at photon at Q^2 up to 14 GeV^2 ?

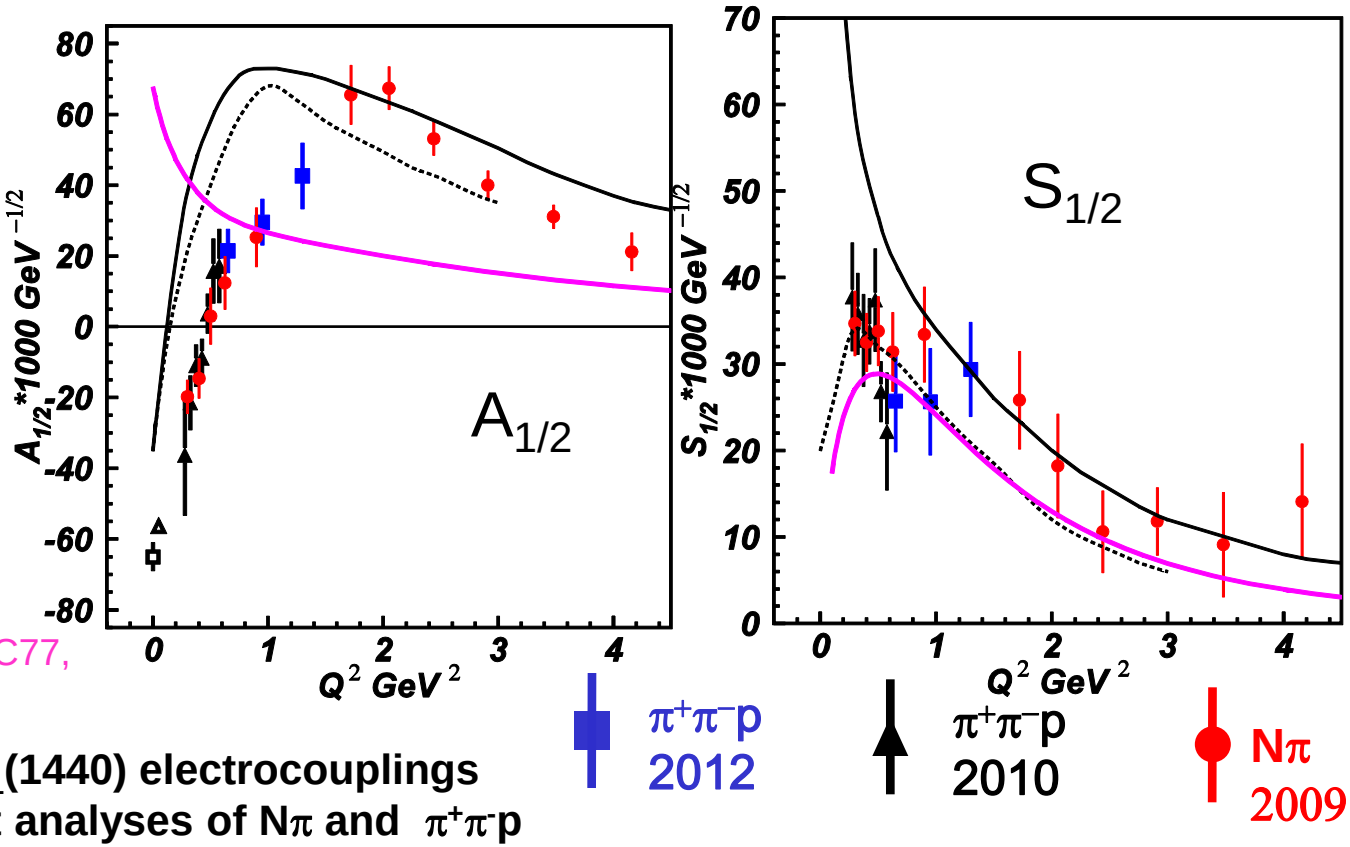
The $P_{11}(1440)$ Electrocouplings from the CLAS Data

LF quark models:

——— I.G.Aznauryan, Phys. Rev . C76, 025212 (2007).

------ S. Capstick and B.D.Keister, Phys.Rev. D51, 3598 (1995).

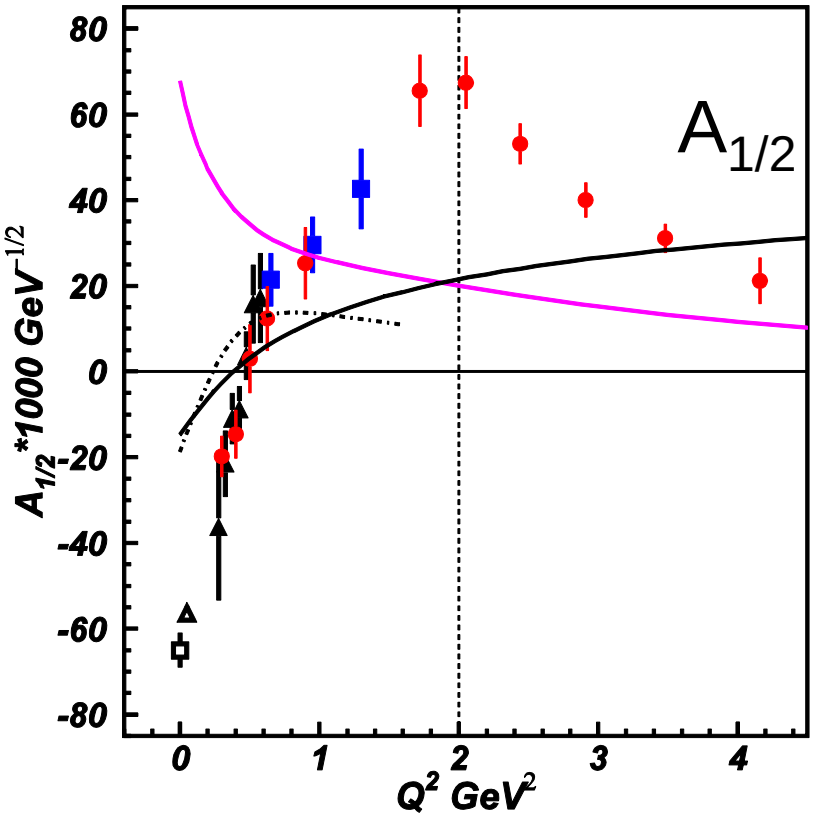
——— EBAC-DCC MB dressing (absolute values). B,Julia-Diaz et al., Phys. Rev. C77, 045205 (2008)



- **Consistent values of $P_{11}(1440)$ electrocouplings determined in independent analyses of Nπ and $\pi^+\pi^-$p exclusive channels strongly support reliable electrocoupling extraction.**

- **The physics analyses of these results revealed the *$P_{11}(1440)$* structure as a combined contribution of: a) quark core as a first *radial excitation of the nucleon 3-quark ground state and b) meson-baryon dressing*.**

Evaluation of $P_{11}(1440)$ electrocouplings within Dyson-Schwinger Equation of QCD (DSEQCD)



Evidence for substantial contributions from meson-baryon cloud .

DSEQCD.
parameterization of the EBAC-DCC bare electrocouplings.
meson-baryon dressing EBAC-DCC (abs. values).

- **Poincare-covariant, symmetry preserving DSEQCD evaluation.**
- **Account for quark mass/structure formation in dressing of bare quark by gluon cloud.**
- **Simplified contact interaction generates momentum independent quark mass.**

D.J.Wilson, et al, Phys. Rev. C85, 025205 (2012).

$$g^2 D_{\mu\nu}(p-q) \Rightarrow \delta_{\mu\nu} \frac{4\pi \alpha_{IR}}{m_G^2}$$

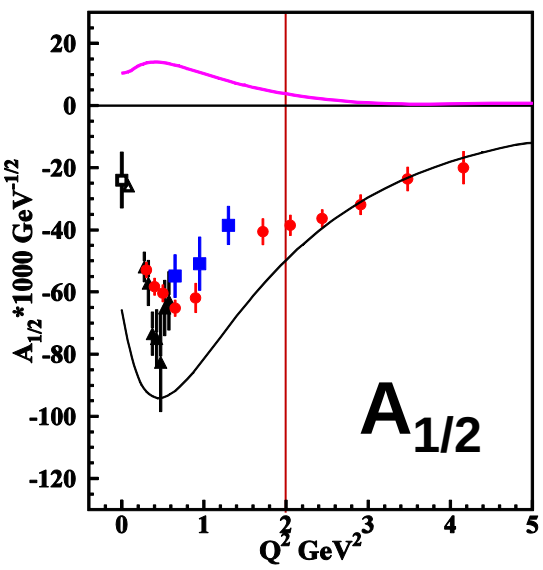
$$\frac{\alpha_{IR}}{4\pi} = 0.93 \qquad m_G = 0.8 GeV$$

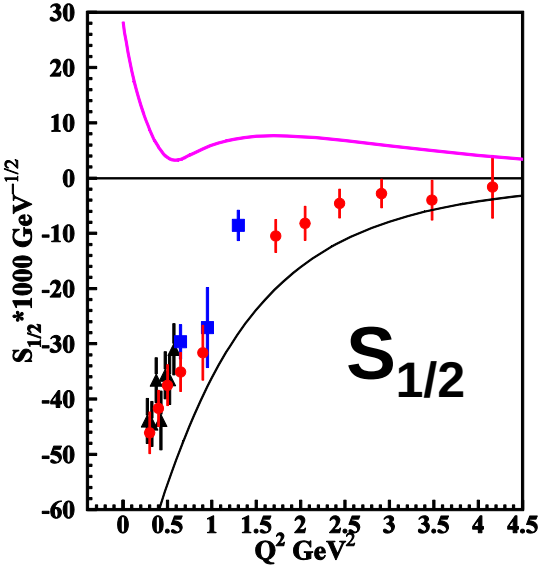
$$m_q^{bare} = 0.007\,GeV \Rightarrow m_q^{dressed} = 0.368\,GeV$$

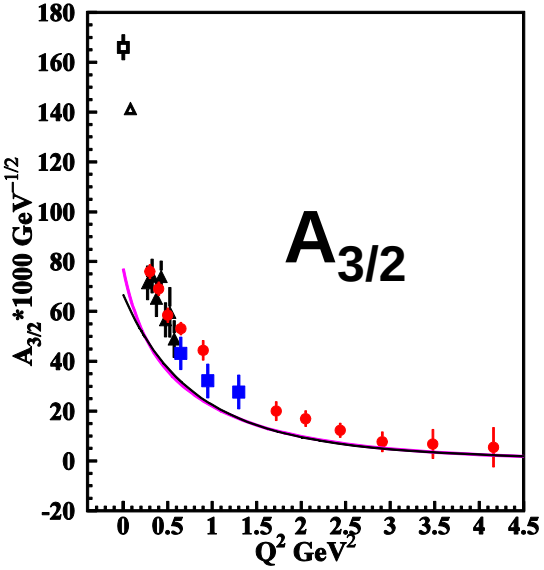
Subject for our Workshop:

Prospects for DSEQCD evaluations $P_{11}(1440)$ electocouplings within a realistic quark-quark interation through the DSEQCD approach and extension for another N* states ⇨ see talk by C.D.Roberts at this Workshop

The $D_{13}(1520)$ electrocouplings from the CLAS data







MB dressing abs val. (EBAC)

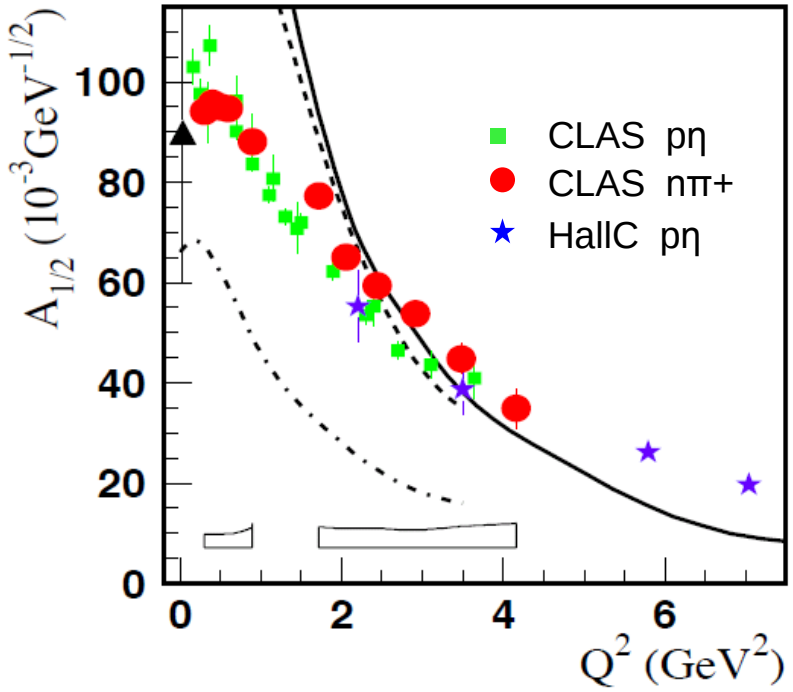
M.Giannini/E.Santopinto hCQM

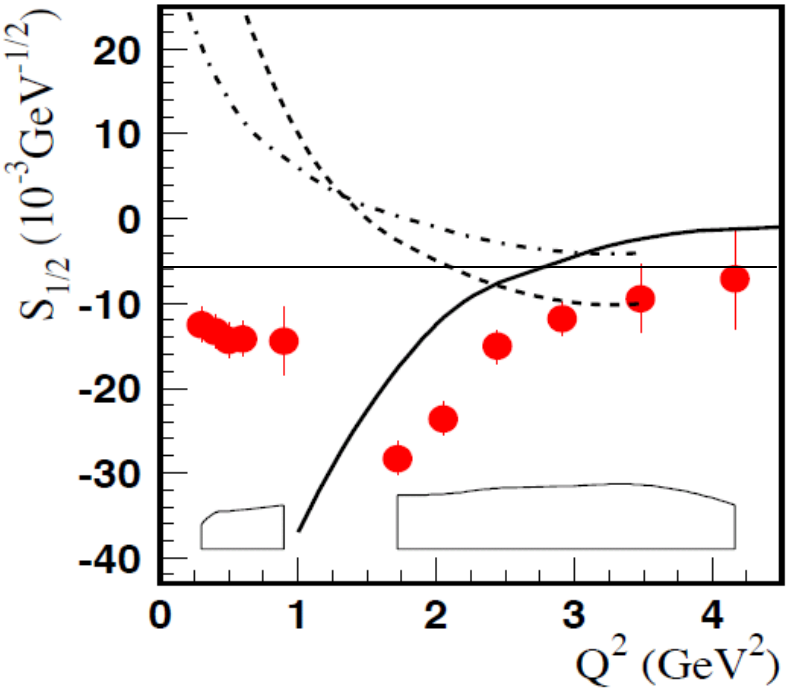
- a reasonable agreement between the results from Nπ and $\pi^+\pi^-$p exclusive channels.
- contributions from 3 dressed quarks in the first orbital excitation and MB cloud combined.
- direct access from experimental data on $A_{1/2}$ electrocoupling at Q^2>2.0 GeV^2 to quark core with negligible contribution from MB cloud.

Subject for our Workshop:

Prospects for evaluation of $D_{13}(1520)$ electrocouplings within the framework of approaches which are explicitly related to QCD at photon virtualities up to 12 GeV^2

S_{11} (1535) electrocouplings and their interpretation





Analysis of pη channel assumes $S_{1/2}$=0
Branching ratios: $\beta_{N\pi} = \beta_{N\eta} = 0.45$

- **$A_{1/2}$ (Q^2) from Nπ and pη are consistent**
- **First extraction of $S_{1/2}$(Q^2) amplitude**

- **LQCD & LCSR calculations (black solid lines) by Regensburg Univ. Group reproduces**
- **data trend at 2.0<Q^2<11.0 GeV^2. V.Braun et al., Phys. Rev. Lett., 103, 072001 (2009) .**

Subject for our Workshop:

Prospects for evaluation of γ_vNN*electrocouplings for other pairs of N* parity partners; access to quark distribution amplitudes in N* states of different quantum numbers.

High lying resonance electrocouplings from the $\pi^+\pi^-p$ CLAS data analysis

Nππ CLAS preliminary.

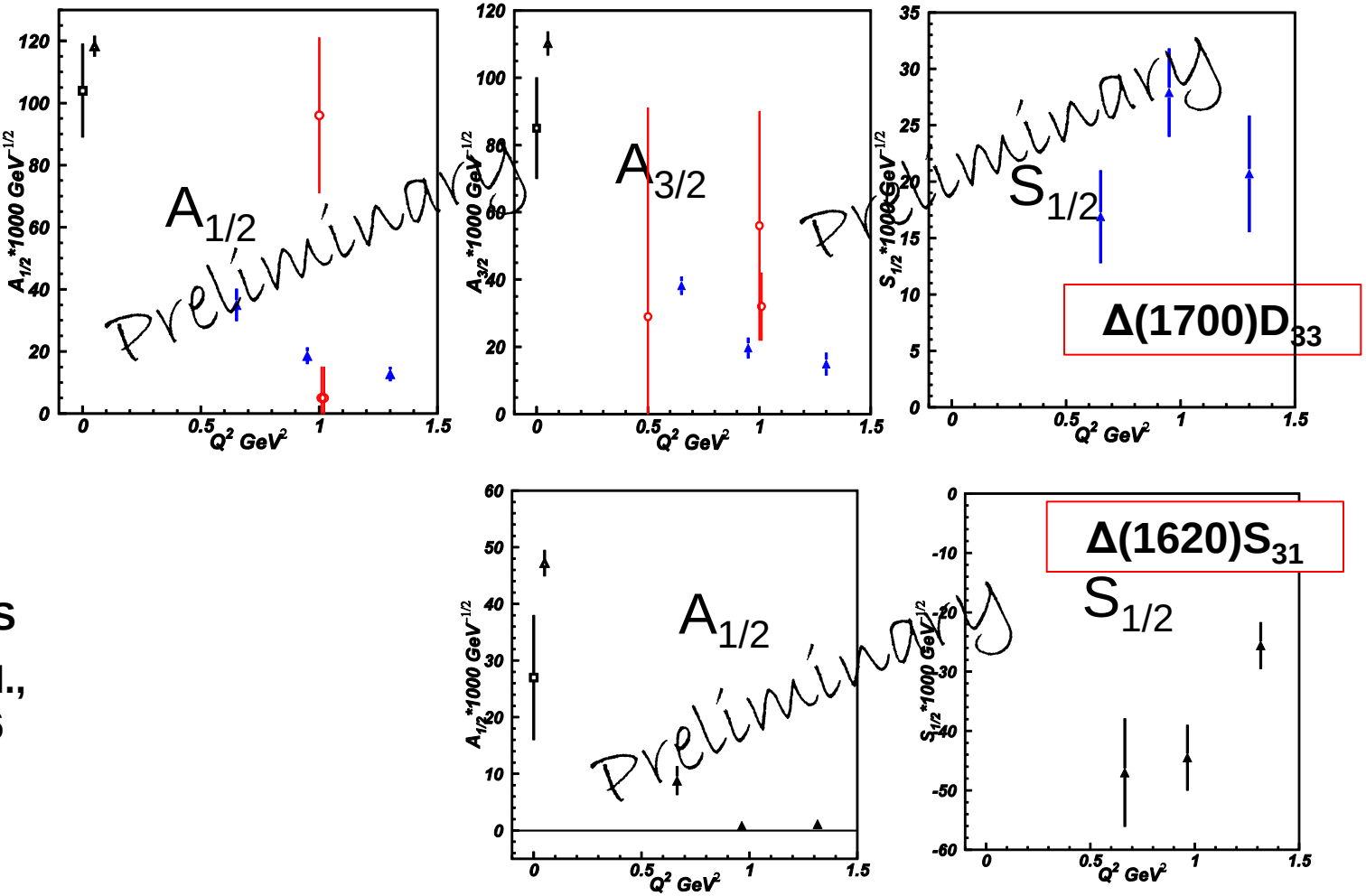
Nπ world

V.D.Burkert, et al., PRC 67, 035204 (2003).

Nπ Q^2=0, PDG.

Nπ Q^2=0, CLAS

M.Dugger, et al., PRC 79,065206 (2009).



•the $\pi^+\pi^-p$ electroproduction channel provided first preliminary results on $S_{31}(1620)$, $S_{11}(1650)$, $F_{15}(1685)$, $D_{33}(1700)$, and $P_{13}(1720)$ electrocouplings of a good accuracy. **Information on electrocouplings of most N* with M_N*<1.8 GeV is available and will be extended in few years up to Q^2=5.0 GeV^2 and at W<3.0 GeV. This considerably extend the scope on baryon structure theory.**

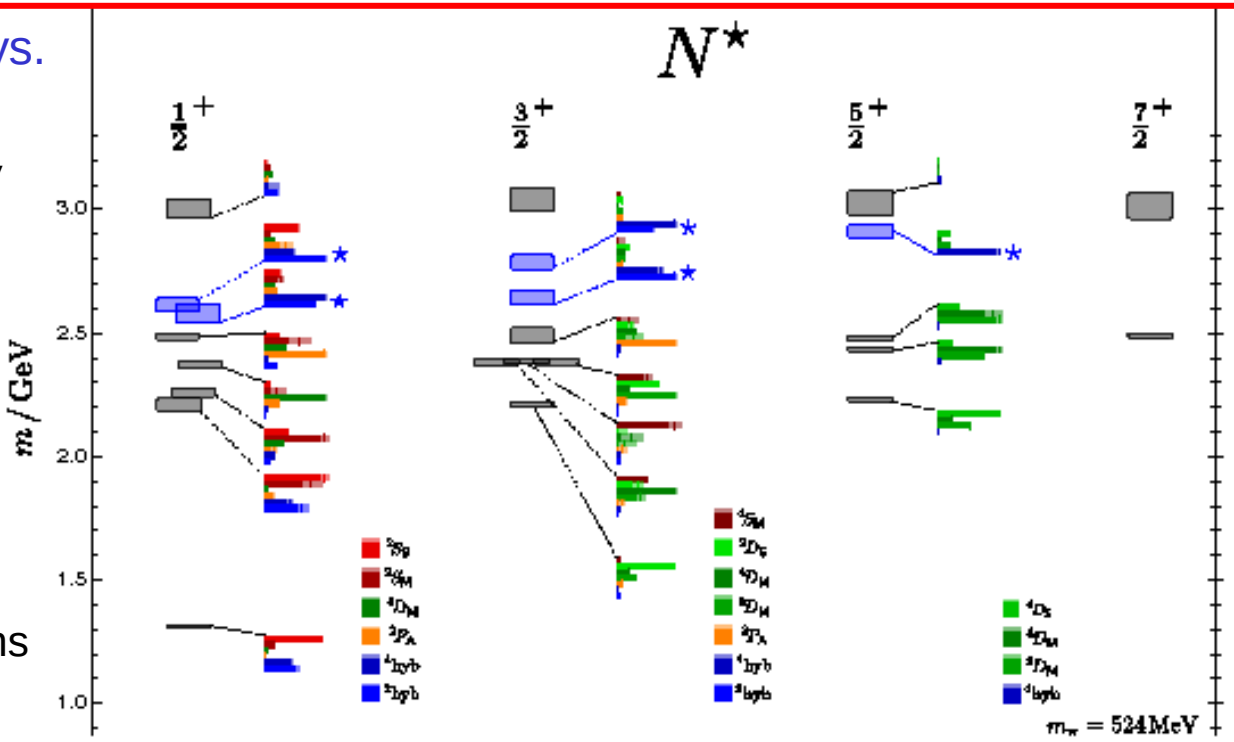
Impact of the Recent LQCD studies of N* Spectrum and Structure on the N* Program with CLAS/CLAS12

J.J.Dudek, R.G.Edwards, Phys. Rev. D85, 054016 (2012).

- each N* state with M_{N^*} <1.8 GeV has partner in computed LQCD spectrum, but level ordering is not always consistent to the data

- wave functions of the low-lying N* states dominate by 1-2 SU(6) configurations, while the wave function of high lying N*'s may contain many SU(6) configurations

- presence of hybrid-N*s with dominant contribution of hybrid components at M_{N^*}>1.9 GeV marked by ★



⇨ Should be verified by experiment !

New direction in N* studies proposed in V.D.Burkert, arXiv:1203.2373 [nucl-ex]: Search for hybrid N*-states looking for:

- **overpopulation of SU(6)-multiplet;**
- **particular behavior of γ_vNN* electrocouplings, which reflects presence of the hybrid component.**

Signals from N* states in the CLAS KY electroproduction data

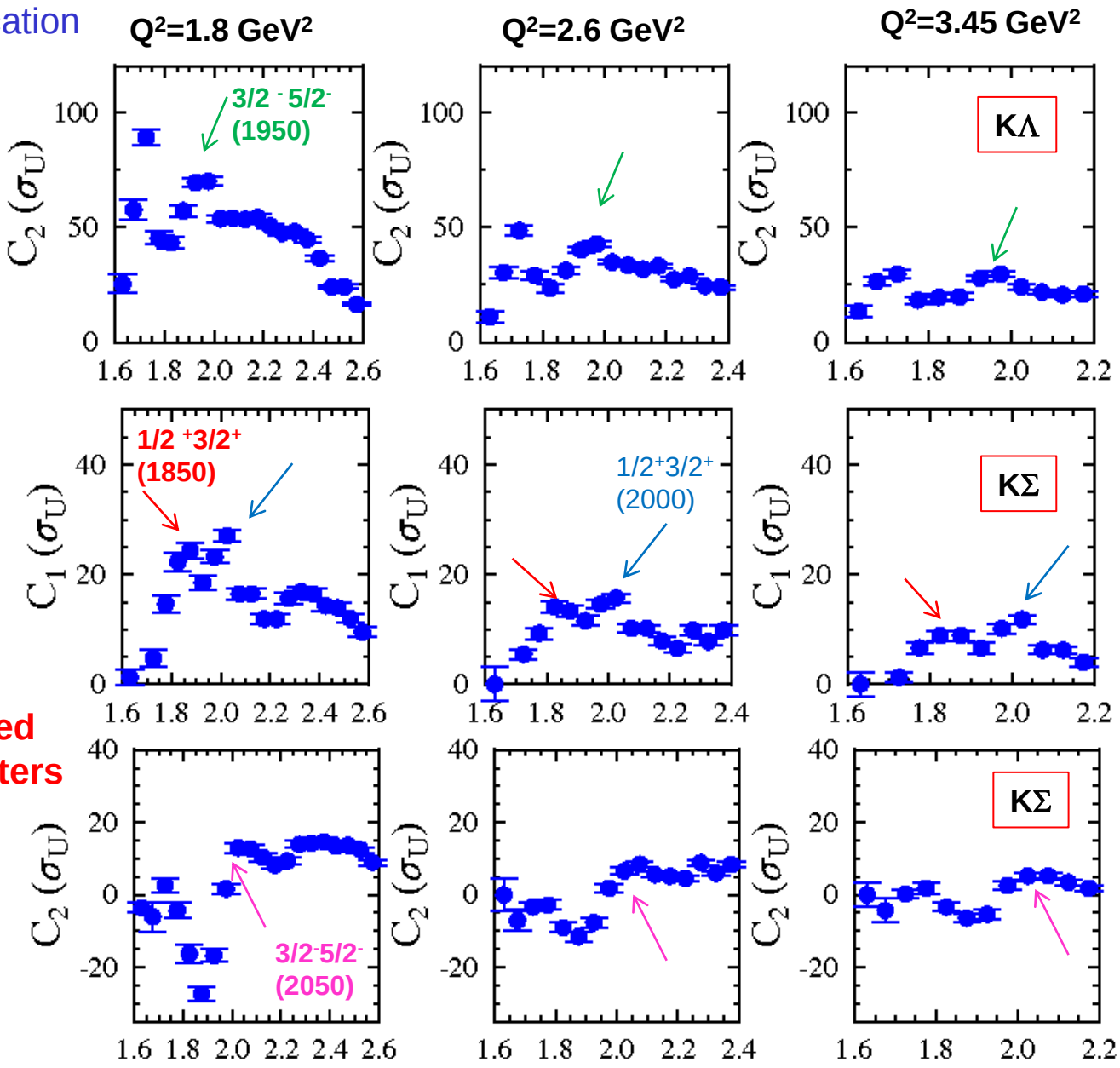
D.Carman, private communication

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

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

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

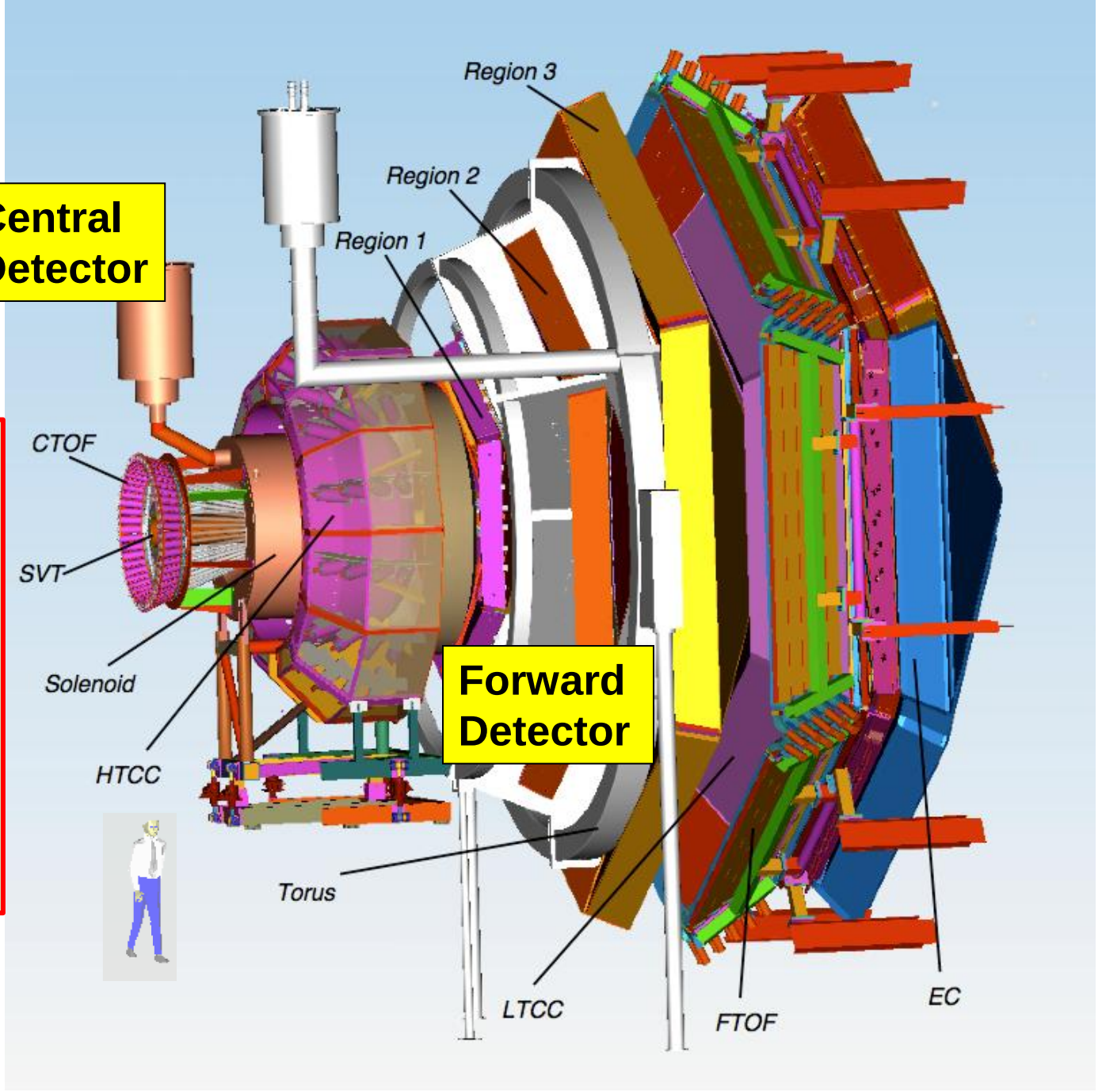


CLAS12

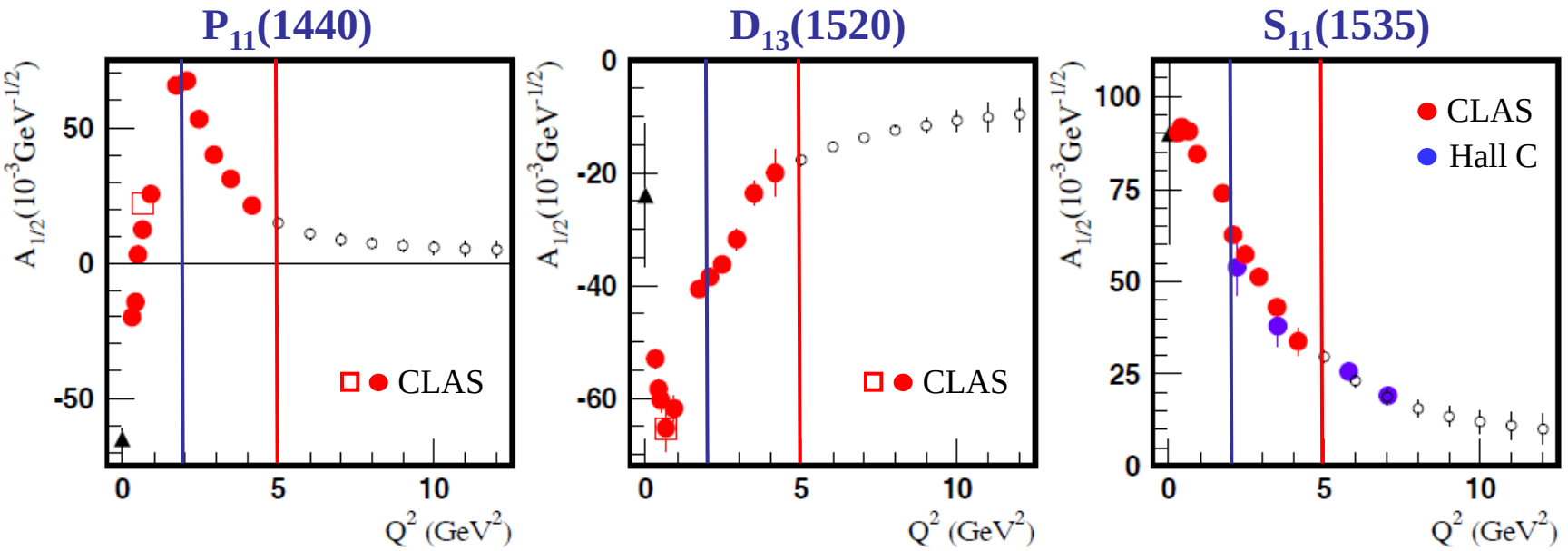
CLAS12 supports a broad program in hadronic physics.

Plans to study excited baryons and mesons:

- Search for hybrid mesons
- Spectroscopy of Ξ^* , Ω^-
- **N* Transition form factors at high Q^2.**



Anticipated N* Electrocouplings from data on Nπ & Nππ electroproduction

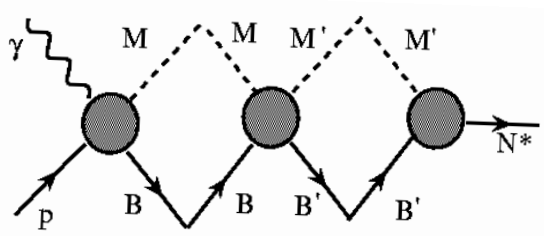


Open circles represent projections and all other markers the available results with the 6-GeV electron beam

- Examples of published and projected results obtained within 60d for three prominent excited proton states from analyses of Nπ and Nππ electroproduction channels. Similar results are expected for many other resonances at higher masses, e.g. $S_{11}(1650)$, $F_{15}(1685)$, $D_{33}(1700)$, $P_{13}(1720)$, …
- This experiment will – for the foreseeable future – be the only experiment that can provide data on $\gamma_v NN^*$ electrocouplings for almost all well established excited proton states at the highest photon virtualities ever achieved in N* studies up to Q^2 of 12 GeV^2.

γ_vNN* Electrocouplings: A Unique Window into the Quark Structure

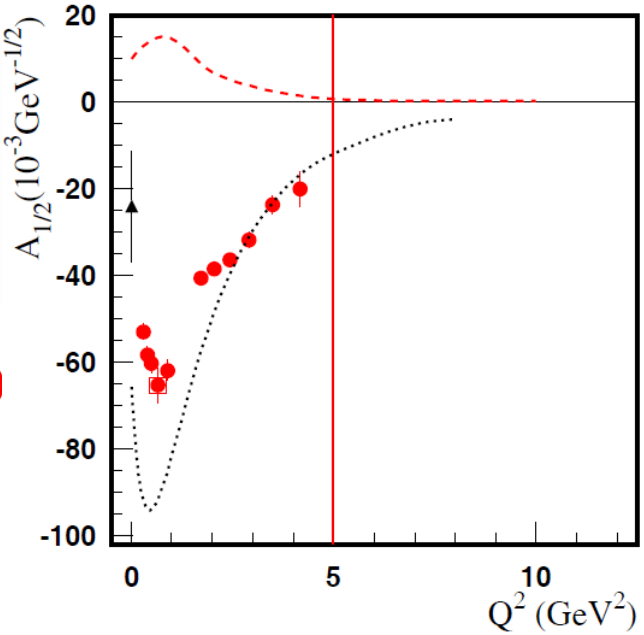
Meson-Baryon Dressing



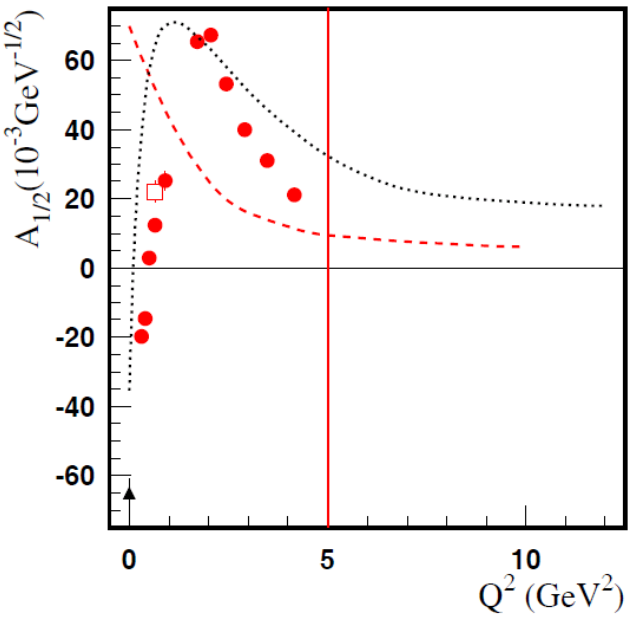
– – – absolute meson-baryon cloud amplitudes (EBAC)

..... quark core contributions (constituent quark models)

$D_{13}(1520)$



$P_{11}(1440)$



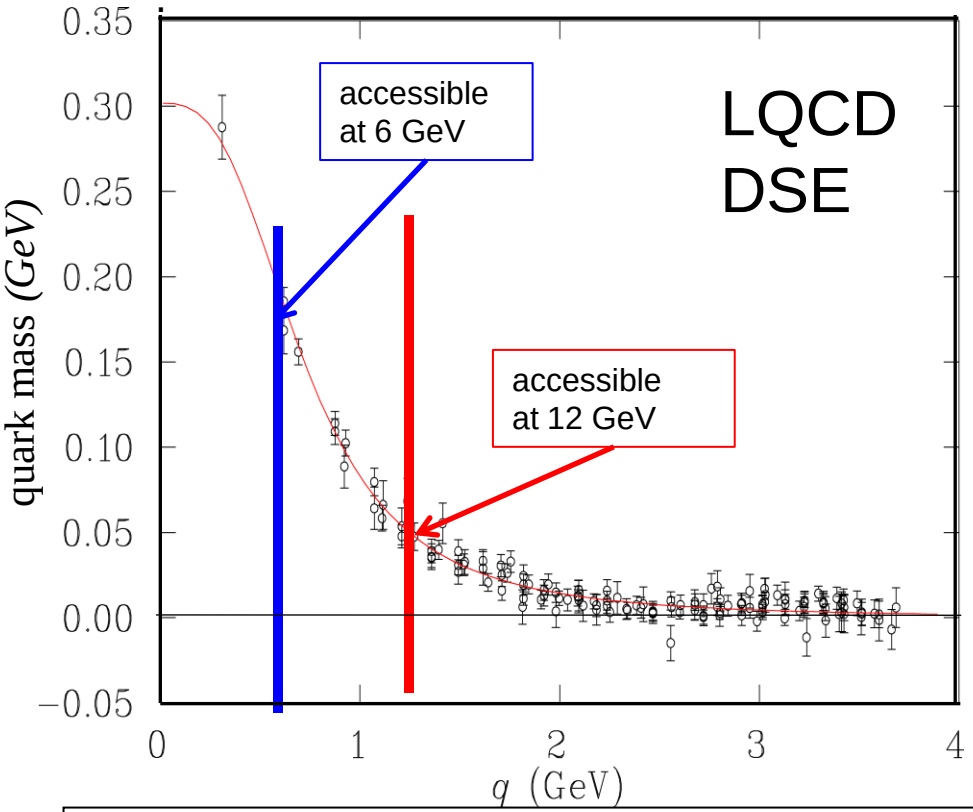
CLAS: Nπ ● and Nπ/Nππ □ combined (Phys. Rev. C80, 055203, 2009)

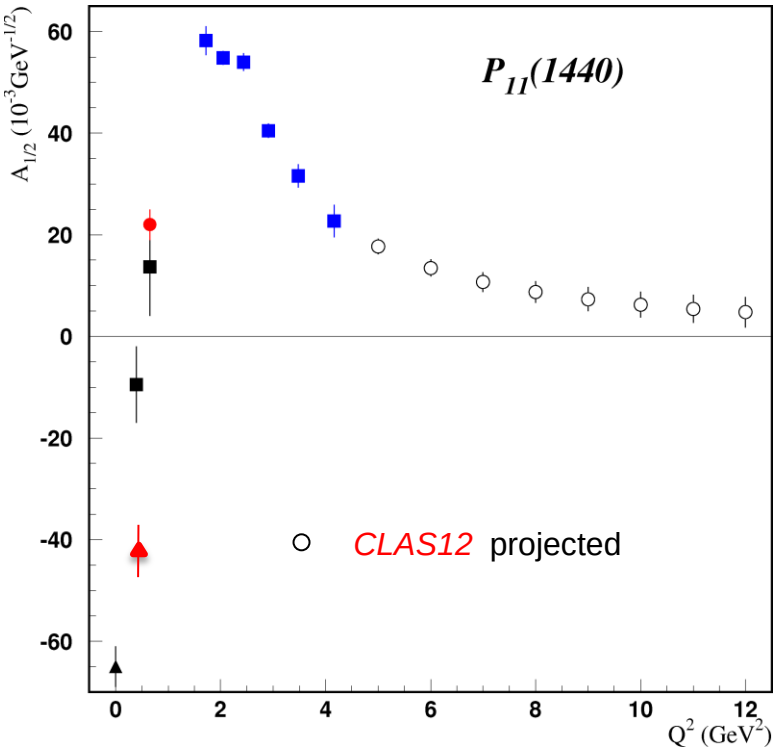
Data on γ_vNN* electrocouplings from E12-09-003 experiment ($Q^2 > 5$ GeV^2) will afford for the first time direct access to the non-perturbative strong interaction among dressed quarks, their emergence from QCD, and the subsequent N* formation.

CLAS12 Resonance Transitions at 12 GeV

Electromagnetic form factors are sensitive to the running quark masses and their dynamical structure

12 GeV experiment E12-09-003 will extend access to transition FF 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.

γ_vNN* Electrocoupling Sensitivity to Momentum Dependent Quark Mass & Structure

colored point with error bars:
available CLAS results on $A_{1/2}$ electrocoupling of $P_{11}(1440)$

$\pi^+\pi^-p$ 2012 | $\pi^+\pi^-p$ 2010 | $N\pi$ 2009

CLAS12 projected

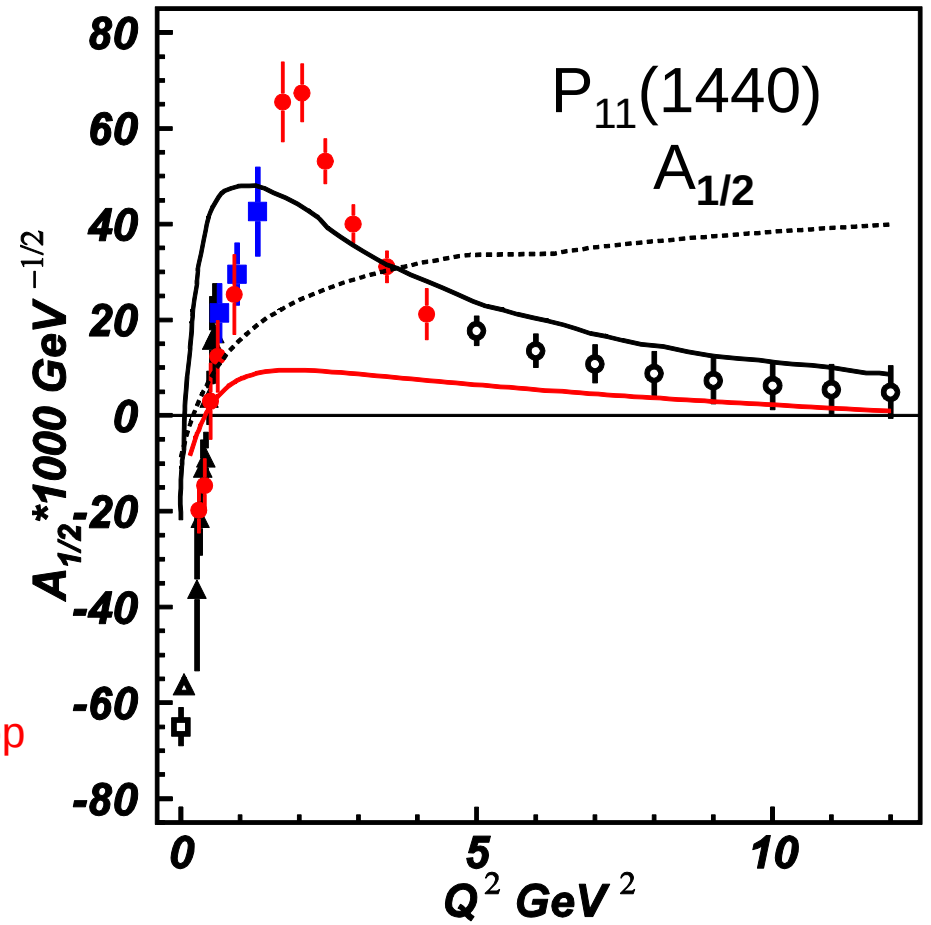
quark core contribution estimated within:

——— LF quark model which employs momentum dependent mass of pointlike quark (F_1=1, F_2=0)
I.G. Aznauryan and V.D.Burkert Phys. Rev. C85, 055202 (2012).

➢See the talk by V.D.Burket at this Workshop

– – – – DSE with contact qq-interaction and momentum independent mass function

——— DSE expectation for QCD qq-interaction and momentum dependent mass function



γ_vNN* electrocouplings measured at the Q^2> 5.0GeV^2 are sensitive to momentum dependence of dressed quark mass and structure.

Reaction Models for Extraction of γ_vNN* Electrocoupling at Q^2>5.0 GeV^2

•All currentl reaction models for extraction of γ_vNN* electrocouplings employ meson-baryon •degrees of freedom . They can be applied at Q^2<5.0 GeV^2, where meson-baryon mechanisms are most relevant.

•The models explicitly account for the transition from meson-baryon to quark degrees of freedom are needed for extracting of γ_vNN* electrocouplings from Nπ and N$\pi\pi$ electroproduction data at 5.0<Q^2<12.0 GeV^2 and W<2.0 GeV.

The starting point:

Description of non-resonant mechanisms in π^+n, π^0p, $\pi\Delta$, and ρp electroproduction channels with the full coverage of reaction phase, including:

- hand-bag diagrams with GPD's structure function from DIS studies;
- reggeized meson-baryon amplitudes;
- color dipole
- others…….

Most urgent need for γ_vNN* electrocpoupling studies with the CLAS12 !

Time scale:

Should be ready by 2015, when E-12-09-003 experiment is scheduled to start the collection of Nπ and N$\pi\pi$ electroproduction data

Conclusions and outlook

- Data on γ_vNN* electrocpouplings of most of the excited proton states in mass range M_{N^*} <1.8 GeV are available from analyses of the CLAS meson electroproduction data at photon virtualitues Q^2 <5.0 GeV^2 for single meson and at Q^2<1.5 GeV^2 for double pion electroproduction. The files with numerical results can be requested from V.Mokeev (mokeev@jlab.org).

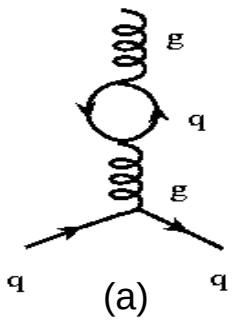
- γ_vNN* electrocpoupling of most excited proton states in mass range up to 2.0-3.0 GeV will become available in future from analyses of both single and double pion electroproduction off protons at photon virtualities up to 5.0 GeV^2.

- CLAS data on KY electroproduction are important for the studies high-lying N* elecgtrocouplings. Reaction models for KY channels are needed.

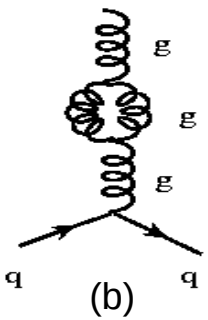
- **The CLAS12 detector is key for the N* Program .** Reaction models for extraction of γ_vNN* electrocpoupling from Nπ & N$\pi\pi$ electroproduction off protons at 5.0<Q^2<12.0 GeV^2 should be ready by 2015.

- Discussions at our Workshop will help on focusing on the where we need to go from here.

Major features of strong interaction in non-perturbative regime



(a)

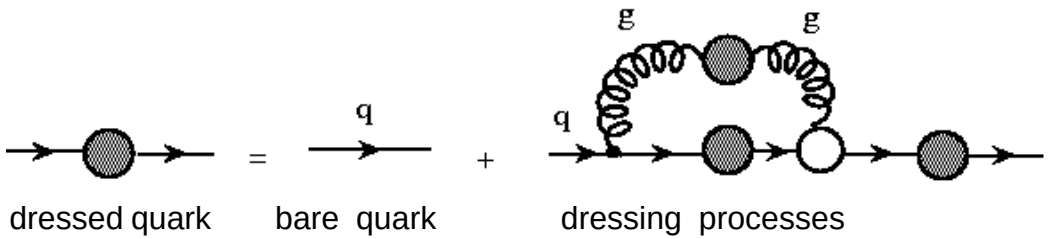


(b)

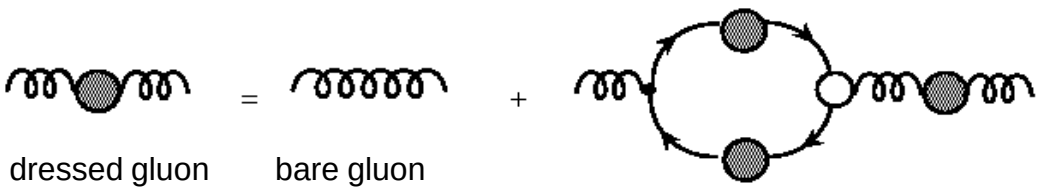
$$\alpha_s(Q^2) = \frac{12\pi}{(33 - 2n_f)\ln\frac{Q^2}{\Lambda^2}}$$

- quark-gluon running coupling α_s increases with distance
- anti- screening (b) prevails screening (a)
- $\alpha_s \sim 1$ as $Q^2 \rightarrow$ few GeV^2

Generation of dressed quarks and gluons



dressed quark bare quark dressing processes



dressed gluon bare gluon dressing processes

Dressing contribution ~ $(\alpha_s)^{N/2}$ (N stands for the number of interaction vertices) . Becomes dominant for the light u and d quarks and gluons as $\alpha_s \sim 1$

Dressed quarks and gluons acquire dynamical, momentum (distance) dependent masses, structure, and quark-gluon interaction amplitudes

- **Quark/Gluon Confinement**
- **Dynamical Chiral Symmetry Breaking**