Experimental studies of N* structure from meson electroproduction data

V.I. Mokeev

Cake Seminar at JLAB Theory Center, November 28 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.

N* Program with CLAS

- **Studies of N* spectrum with a focus in the search for new baryon states**

strong support from recent LQCD studies, J.J.Dudek, R.G.Edwards, Phys. Rev. D85, 054016 (2012).

- baryon state spectrum as rich as it was expected in quark models employing SU(6) spin-flavor symmetry;
- presence of hybrid baryons with masses above 1.9 GeV.

bare N* masses were evaluated within the framework of DSEQCD: H.L.L. Roberts, et al., Few Body Syst. 51, 1 (2011):

- incorporates dynamical chiral symmetry breaking;
- reproduces N* state ordering .

Experimental prospects , V.D.Burkert, arXiv:1209.2402 [nucl-ex] :

- evaluation of pseudo scalar meson photoproduction amplitudes from combined studies of unpolarized cross sections and polarization asymmetries;
- almost model independent information on N* spectrum, photo and hadronic couplings from singularities of analytical continuation of produiction amplitudes into a complex energy plane.

- **N* structure from exclusive meson electroproduction data**

Extraction of resonance electroexcitation amplitudes (γ_vNN* electrocouplings) at different photon virtualities Q^2.

Recent review papers:

I.G.Aznauryan and V.D. Burkert, Progr. Part. Nucl. Phys. 67, 1 (2012).

I.G.Aznauryan et al., J.Phys. Conf. Ser. 299, 012008 (2011).

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

Our experimental program seeks to determine

$\gamma_v NN^*$ 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 global multi-channel analyses.

This information is needed to study the non-perturbative strong interaction which generates N* states as 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.

The white paper

I. G. Aznauryan,[1,2] A. Bashir,[3] V. Braun,[4] S. J. Brodsky,[5,6] V. D. Burkert,[2] L. Chang,[7,8] Ch. Chen,[7,9,10] B. El-Bennich,[11,12] I. C. Cloët,[7,13] P. L. Cole,[14] R. G. Edwards,[2] G. V. Fedotov,[15,16] M. M. Giannini,[17,18] R. W. Gothe,[15] Huey-Wen Lin,[19] P. Kroll,[20,4] T.-S. H. Lee,[7] W. Melnitchouk,[2] V. I. Mokeev,[2,16] M. T. Peña,[21,22] G. Ramalho,[21] C. D. Roberts,[7,10] E. Santopinto,[18] G. F. De Teramond,[23] K. Tsushima,[24] and D. J. Wilson[7,25]

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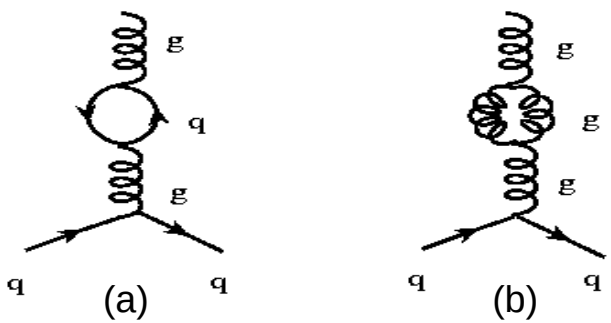
Theory support for the studies of N* structure with the CLAS12 detector

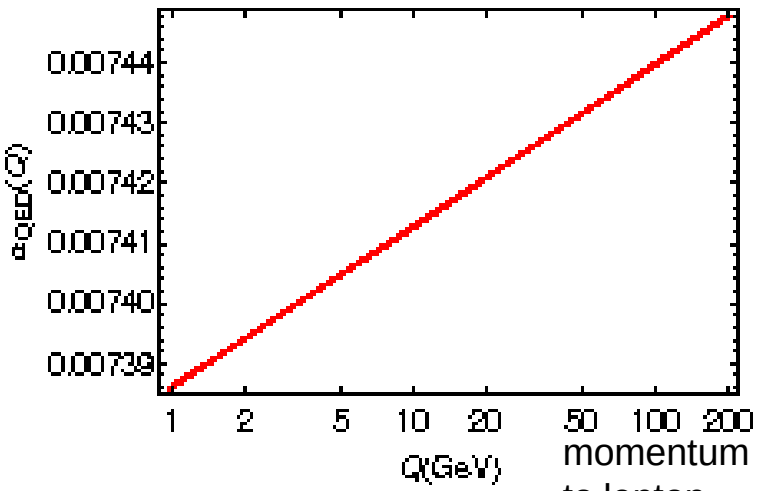
The Nature of Strong (non-perturbative) QCD regime



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

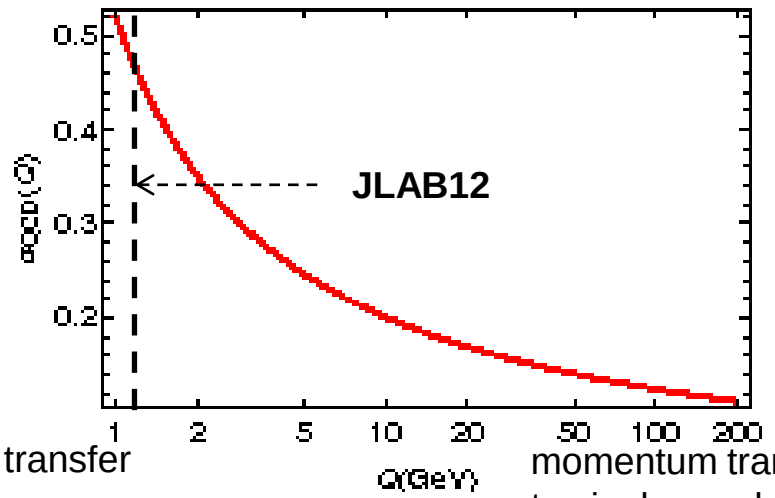
- quark-gluon running coupling α_s increases with distance
- anti- screening (b) takes over screening (a)
- $\alpha_s \sim 1$ as $Q^2 \rightarrow$ few GeV^2

QED coupling



momentum transfer to lepton

QCD coupling

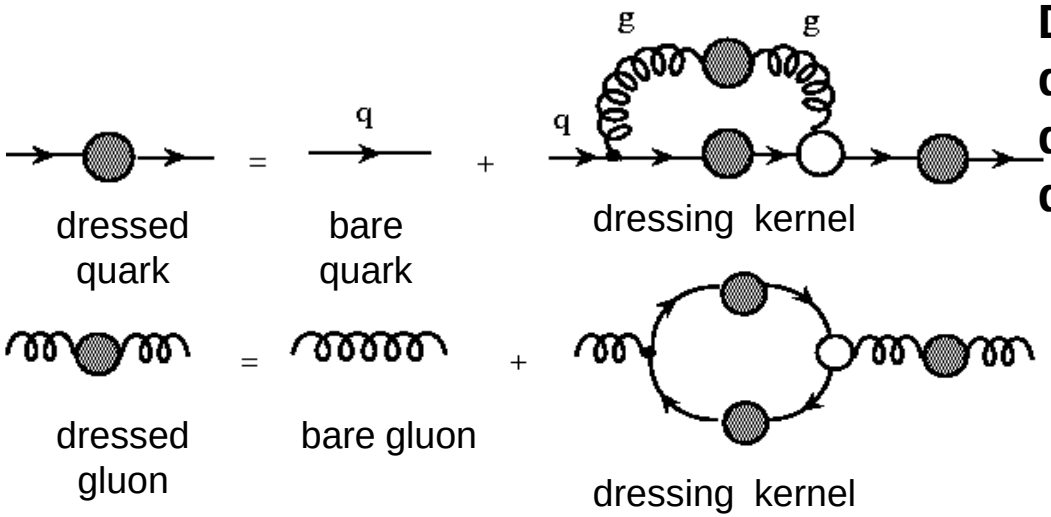


momentum transfer to single quark

On the same momentum domain, the QCD coupling changes 500,000-times more that the QED coupling and run in the opposite direction.

Particular features of strong interaction in non-perturbative regime

Generation of dressed quarks and gluons



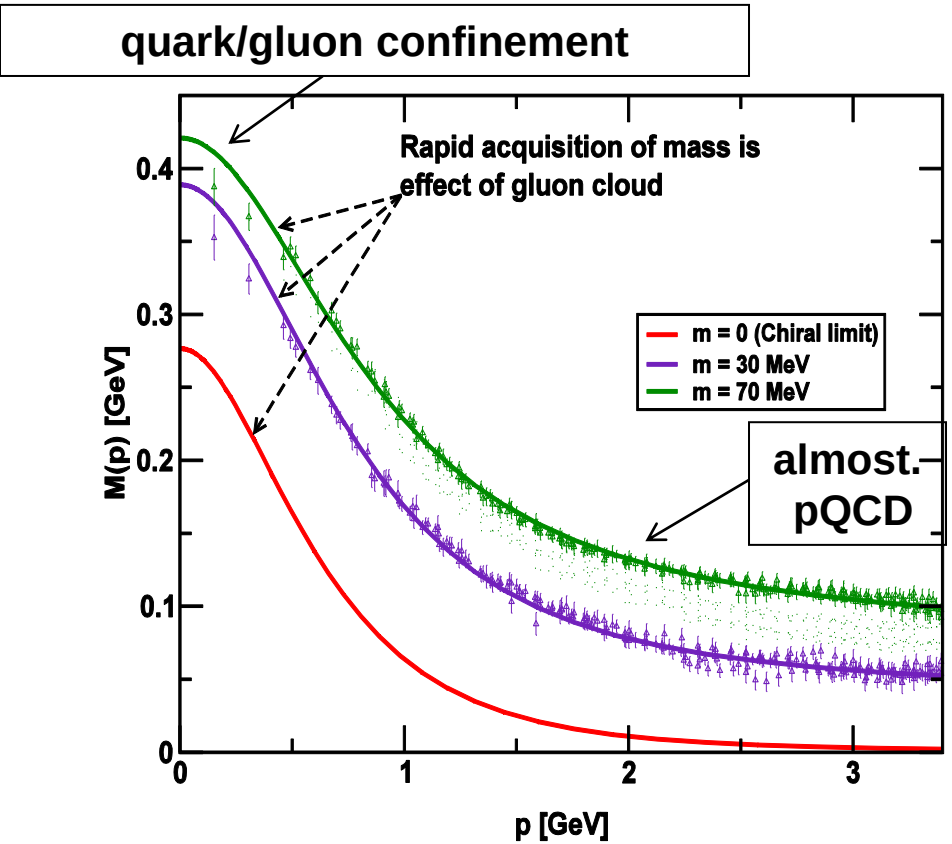
Dressed quarks and gluons acquire dynamical, momentum (distance) dependent masses, structure, and quark-gluon interaction amplitudes

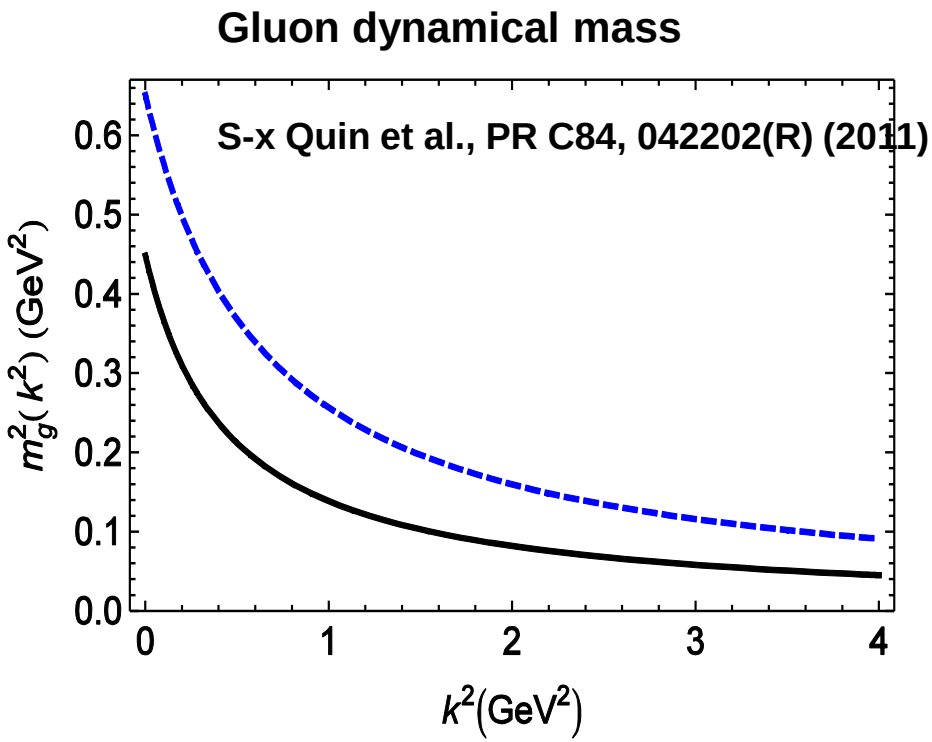
- **Quark/Gluon Confinement**
- **Dynamical Chiral Symmetry Breaking**

Can not be described within the framework of pQCD!

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 $\alpha_s \sim 1$

Dynamical mass and structure of dressed quarks and gluons





- > 98% of dressed quark/gluon and N* masses and their dynamical structure are generated non-perturtbatively 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, and will provide access to dressed quark dynamical structure.
- the momentum dependence of the dressed quark mass reflects the transition from quark/gluon confinement to pQCD .

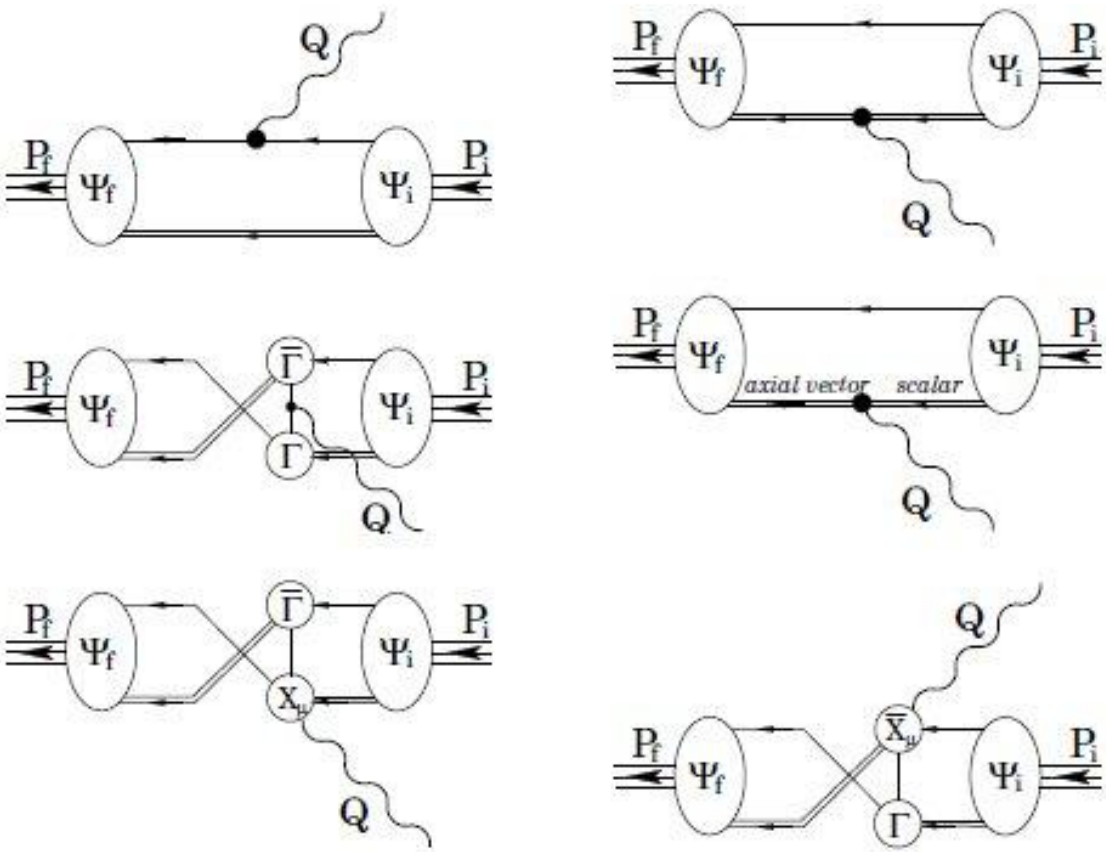
$\gamma_v NN^*$ electrocouplings as a window to strong interactions in non-perturbative region

Quark core contribution to $\gamma_v NN^*$ electrocouplings

•quark propagators are sensitive to the quark running mass M(p);

•dressed quark e.m. current is sensitive to the quark dynamical structure;

•quark interaction vertices Γ and X are sensitive to the quark non-perturbative interactions.



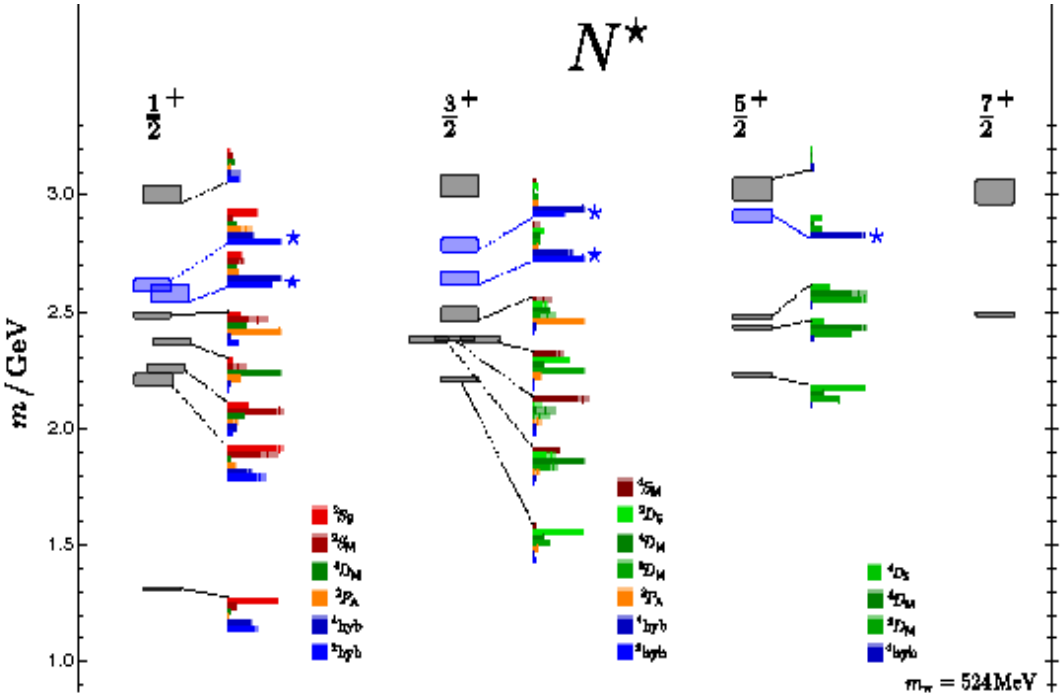
•Data on $\gamma_v NN^*$ electrocouplings at different Q^2 probe momentum dependence of dynamical quark mass, structure, and non-perturbative qq-interactions.

•A key direction in exploration of quark/gluon confinement and DCSB in baryons.

Why studies of ground and excited nucleon states combined are needed?

Di-quark J^{π}	Ground state	P_{11} $\frac{1}{2}^{+}$(1440)	S_{11} $\frac{1}{2}^{-}$(1535)	S_{11} $\frac{1}{2}^{-}$(1650)
0^{+}	77%			
1^{+}	23%	100%		
0^{-}			51%	43%
1^{-}			49%	57%

Di-quark content of ground and N* states from DSEQCD with vector x vector interaction, C.D.Roberts et al., AIP Conf. Proc. 1432, 309 (2012).

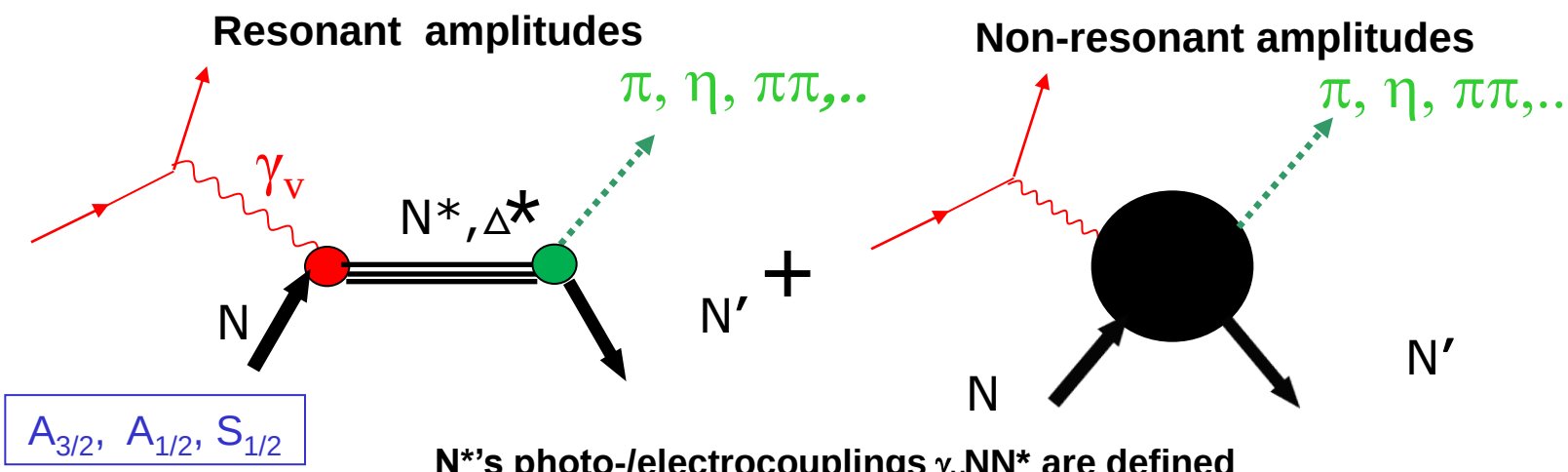


N* spectrum and structure from LQCD, J.J.Dudek, R.G.Edwards, Phys. Rev. D85, 054016 (2012).

- **N* states of different quantum numbers offer complementary information on mechanisms of baryon generation from quarks and gluons.**

- **N* electrocouplings allow us to explore strong regime of QCD at larger transverse distances with larger α_{QCD} than the ground state form factors.**

Extraction of $\gamma_v NN^*$ electrocouplings from the data on exclusive meson electroproduction off protons



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

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

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

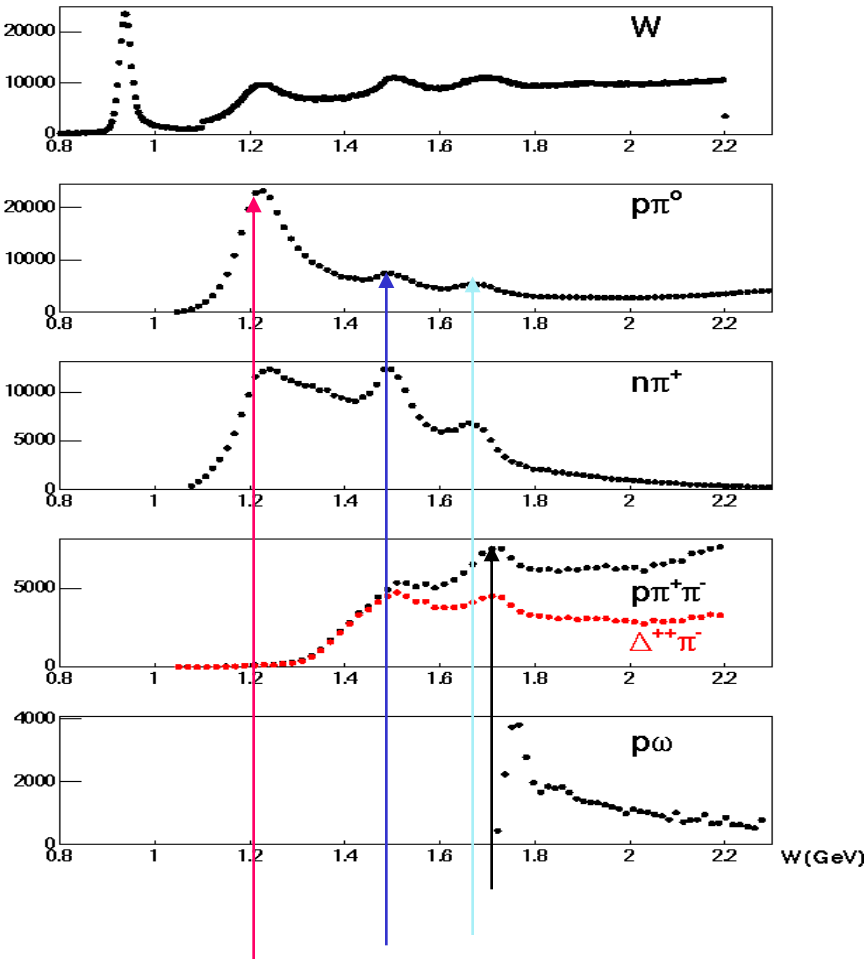
- **Consistent results on $\gamma_v NN^*$ electrocouplings from different meson electroproduction channels demonstrate reliable extraction of N* parameters.**

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



Approaches for extraction of $\gamma_v NN^*$ electrocouplings from the CLAS data on exclusive meson electroproduction

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

➢ $\pi^+ n$ and $\pi^0 p$ 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., Phys. Rev. C86, 035203 (2012).

- **Global coupled-channel analyses of the CLAS/world data of πN, $\gamma_v N \rightarrow \pi N$, ηN, $\pi\pi N$, $K\Lambda$, $K\Sigma$ exclusive channels:**

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

Further developments by Argonne-Osaka Collaboration are in progress:
www.jlab.org/conferences/EmNN2012/

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

Number of data points >125,000, W<1.7 GeV, $0.15<Q^2<6.0$ GeV^2, almost complete coverage of the final state phase space.

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

Electrocoupling extraction:
I.G.Aznauryan,
V.D.Burkert et al.
(CLAS Collaboration), PR C80, 055203 (2009).

Recent data extension:

π^+n
$1.6< W<2.04$ GeV, $1.5<Q^2<4.5$ GeV^2
K.Park private comm.

π^0n
$1.1< W<1.8$ GeV, $0.5<Q^2<1.0$ GeV^2
N.Markov private comm.

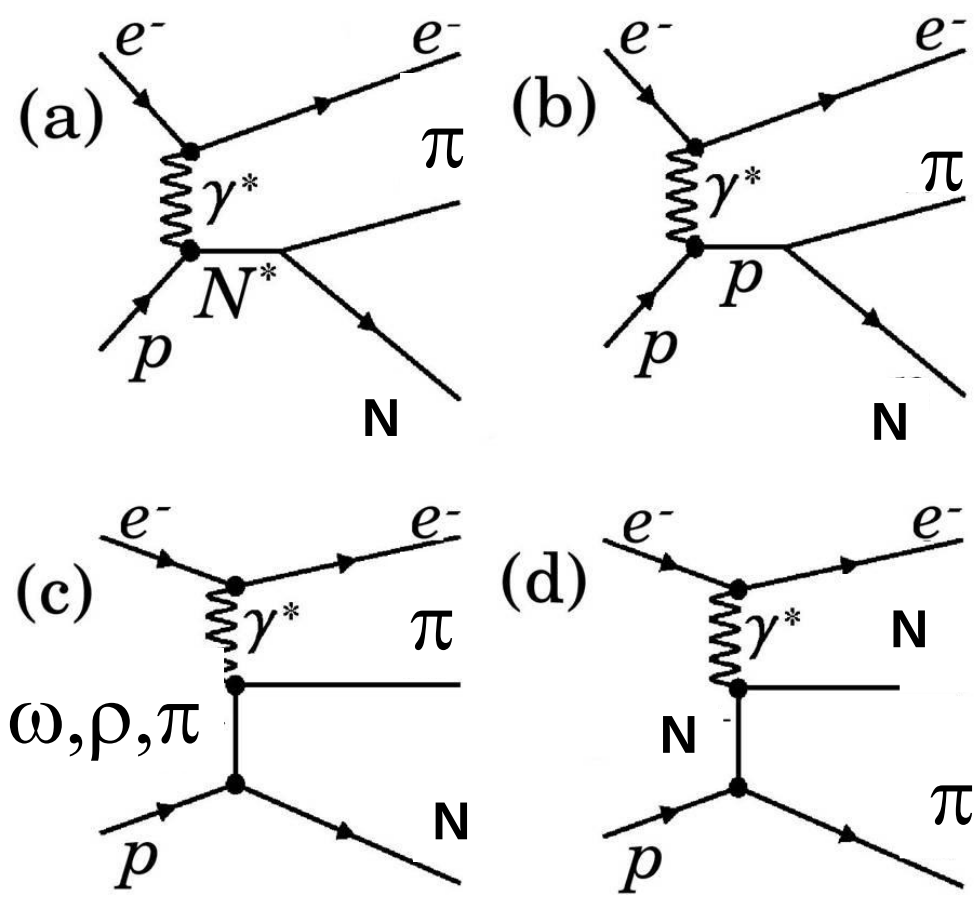
The approaches for extraction of $\gamma_v NN^*$ electrocouplings from $N\pi$ exclusive electroproduction off protons

The Model based on fixed-t Dispersion Relations (DR)

Unitary Isobar Model (UIM)

•the real parts of 18 invariant Ball $N\pi$ electroproduction amplitudes are computed from their imaginary parts employing model independent fixed-t dispersion relations;

•the imaginary parts of the Ball $N\pi$ electroproduction amplitudes at W>1.3 GeV are dominated by resonant parts and were computed from N* parameters fit to the data.

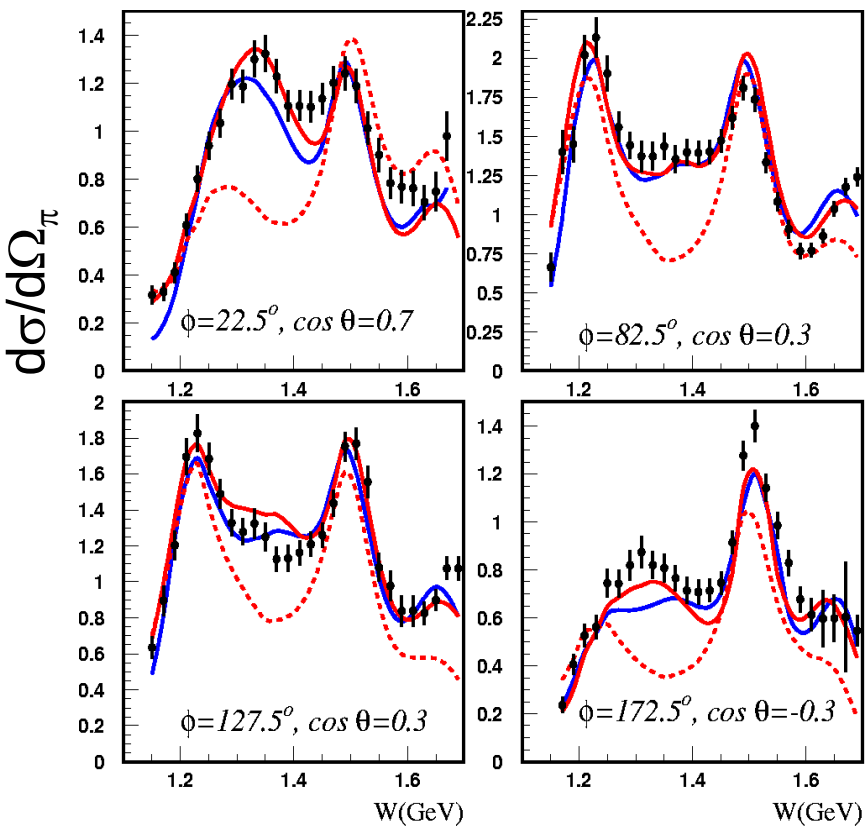


I. G. Aznauryan, Phys. Rev. C67, 015209 (2003), I.G.Aznauryan, V.D.Burkert, et al. (CLAS Collaboration), PRC 80. 055203 (2009).

Fits to $\gamma p \to \pi^+ n$ differential cross sections and structure functions

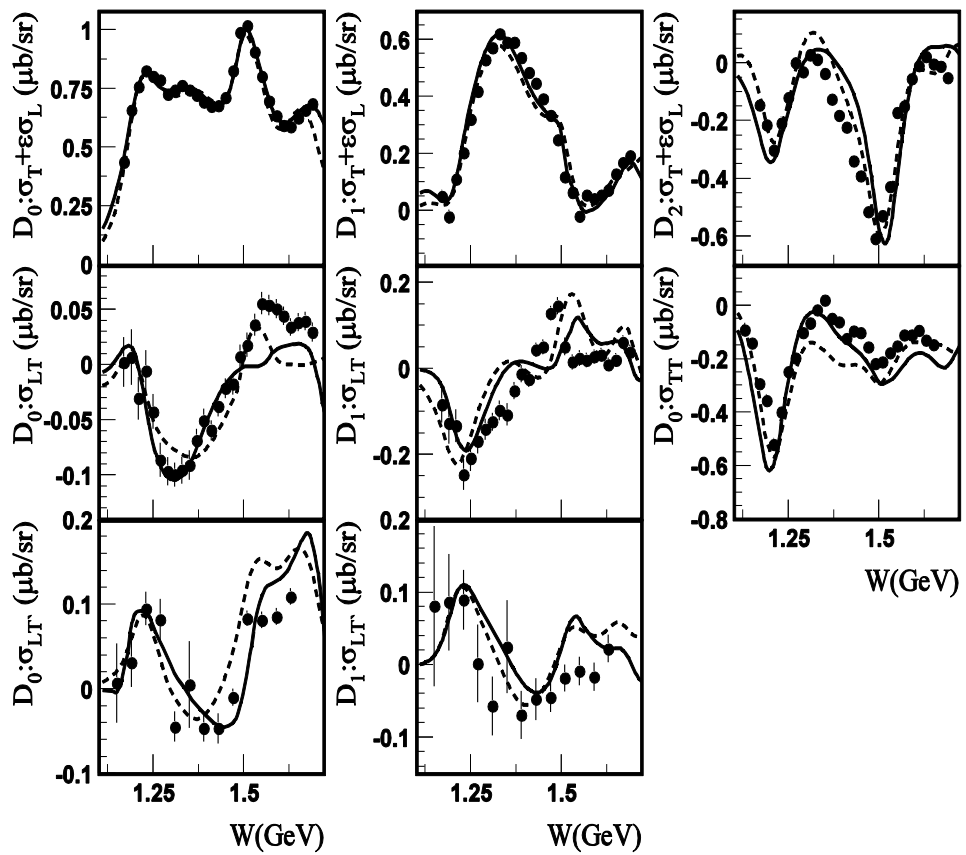
Q^2=2.05 GeV^2

DR
DR w/o P11
UIM



Q^2=2.44 GeV^2

DR
UIM

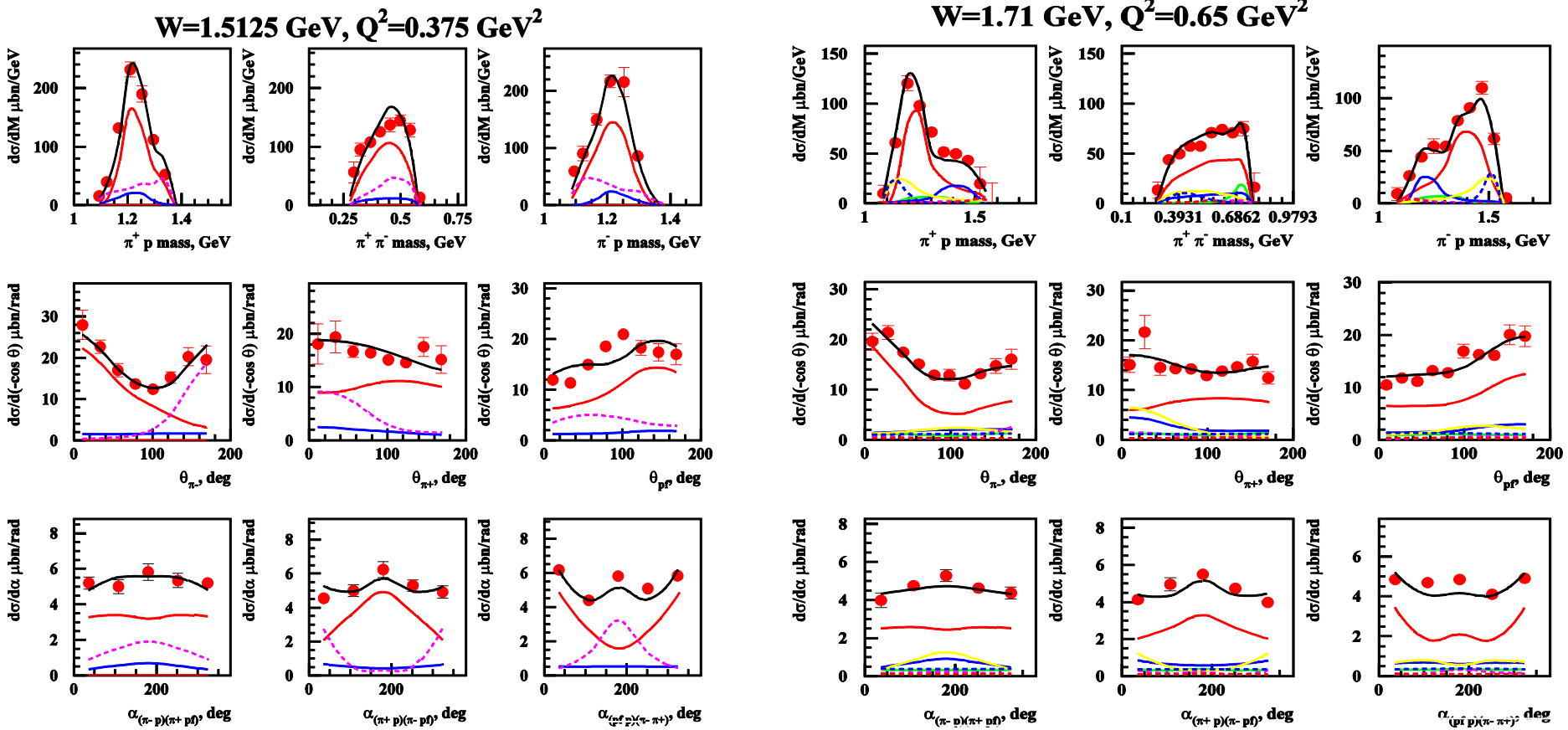


L=0 Legendre moments from various structure functions

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

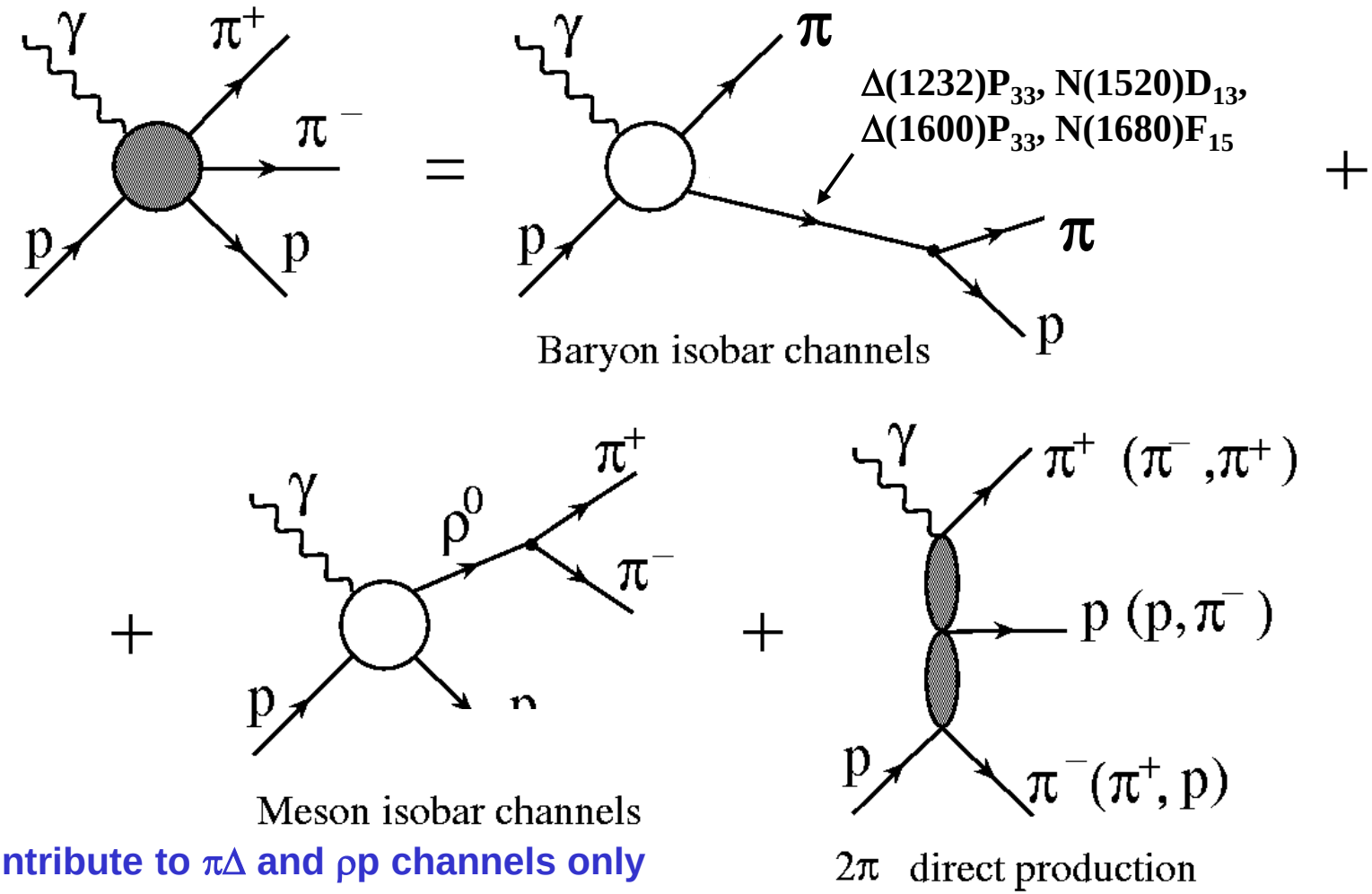


full JM calc. — $\pi^+\Delta^0$ — ρp — $\pi^+F^0_{15}(1685)$

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

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

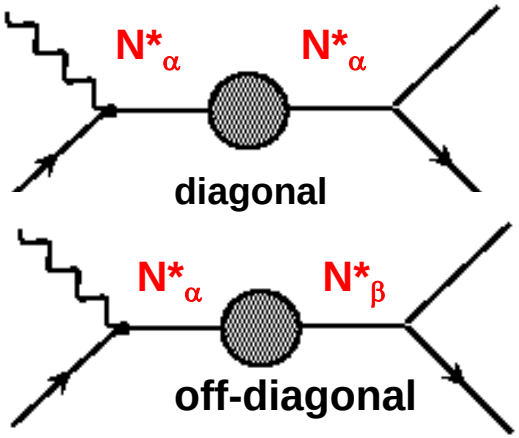
Major objectives: extraction of $\gamma_v NN^*$ electrocouplings and $\pi\Delta$, ρp decay widths.



N* contribute to $\pi\Delta$ and ρp channels only

Unitarized Breit-Wigner ansatz for resonant amplitudes

Developed based on approach: I.J.R.Aitchison, Nuclear Physics , A189 (1972), 417.



Inverse of the JM unitarized N* propagator:

$$S^{-1}_{\alpha\beta} = M^2_{N^*}\delta_{\alpha\beta} - i\left(\sum_i \sqrt{\Gamma_{\alpha i}}\sqrt{\Gamma_{\beta i}}\right)\sqrt{M_{N^*\alpha}}\sqrt{M_{N^*\beta}} - W^2\delta_{\alpha\beta}$$

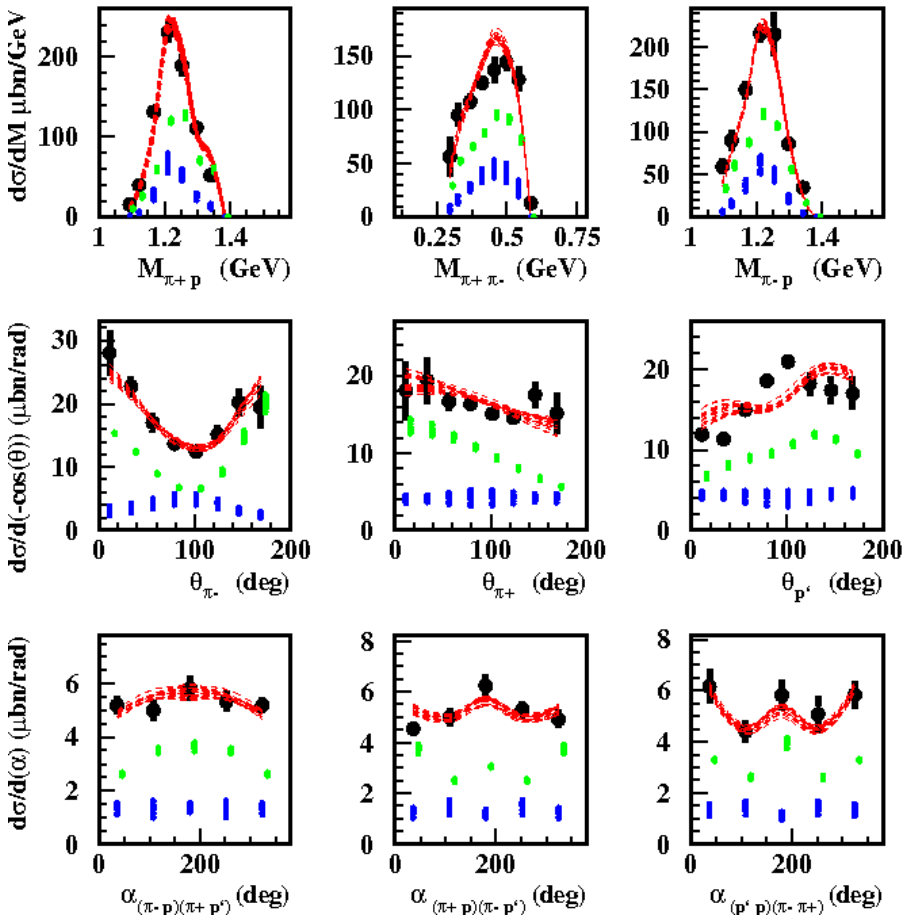
Off-diagonal transitions incorporated into the full resonant amplitudes of the JM model:

$S_{11}(1535) \leftrightarrow S_{11}(1650)$
$D_{13}(1520) \leftrightarrow D_{13}(1700)$
$3/2^+(1720) \leftrightarrow P_{13}(1700)$

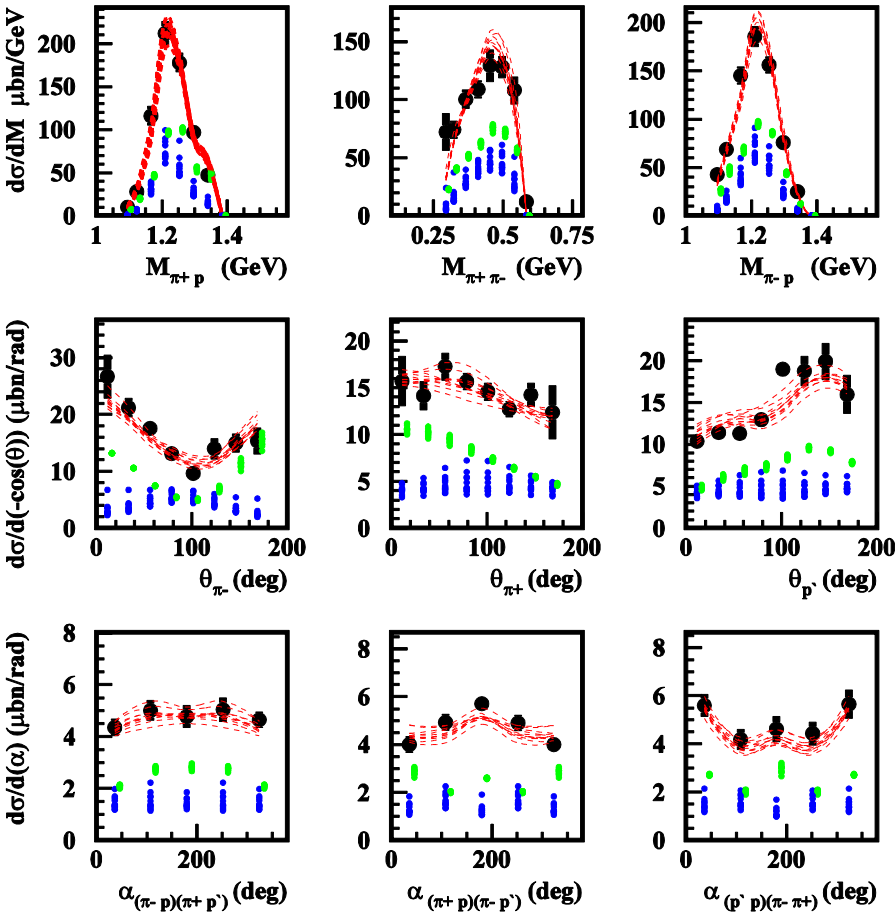
Full resonant amplitude of unitarized Breit-Wigner ansatz is consistent with restrictions imposed by a general unitarity condition, as well as with the resonant Argonne-Osaka ansatz in on-shell approximation.

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

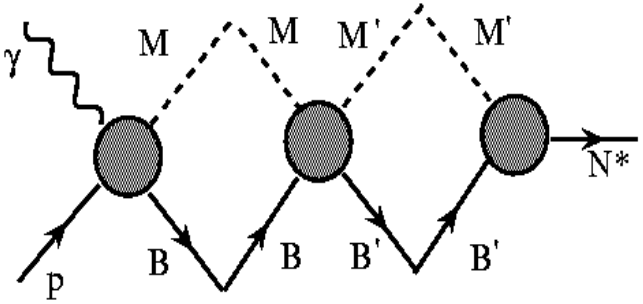
full cross sections within the JM model

resonant part

non-resonant part

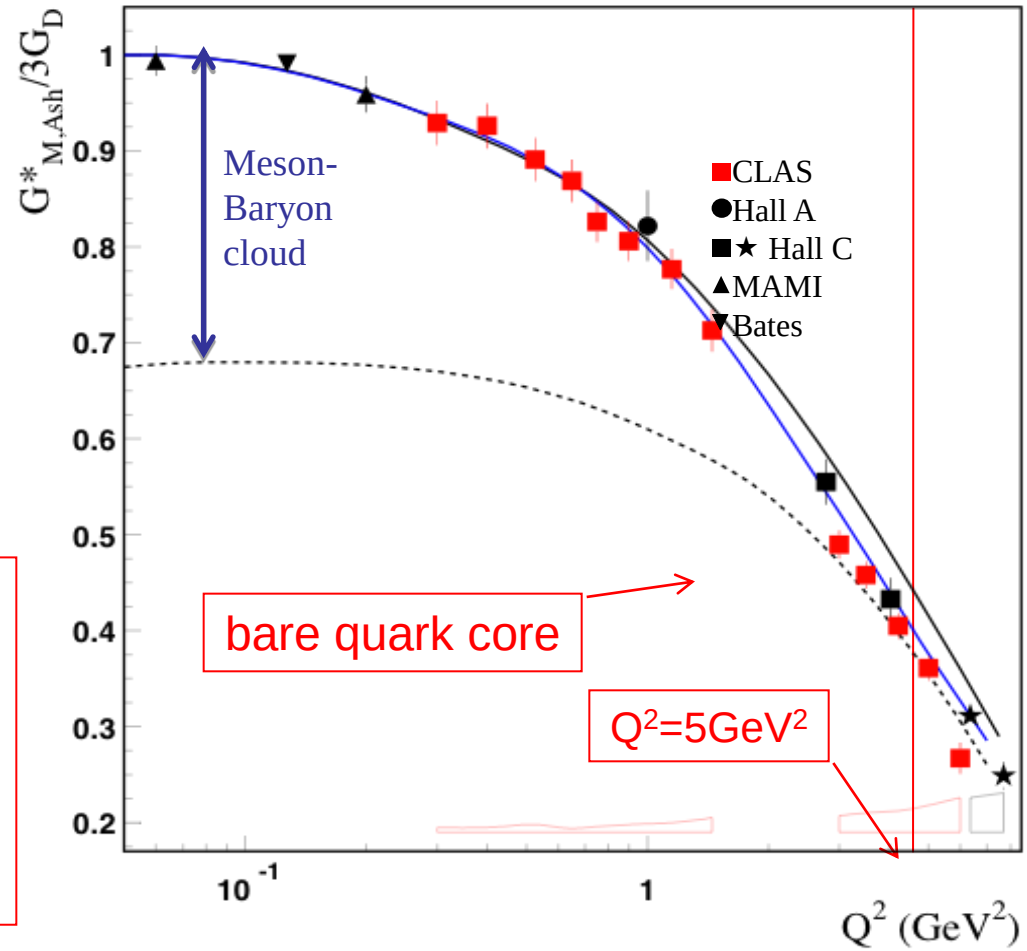
NΔ Transition Form Factor – $G_{M.}$ Meson-baryon dressing vs Quark core contribution from EBAC-DCC/Argonne-Osaka analysis.

- 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

Whether MB-dressing helps us to understand local/global parton-hadron duality?



Could we observe the transition to pQCD in Q^2 –range up to 14 GeV^2 ?

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

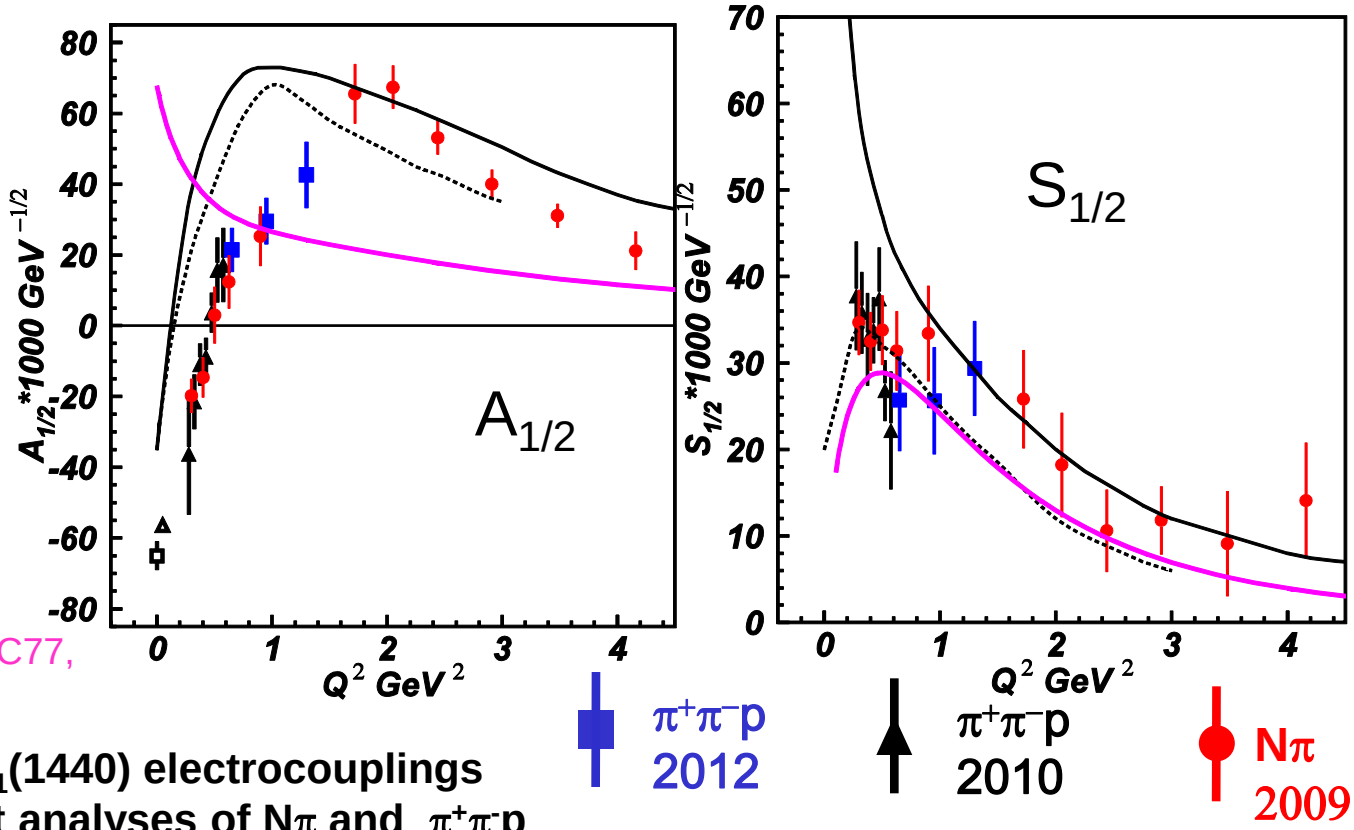
LF quark models:

——— 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).

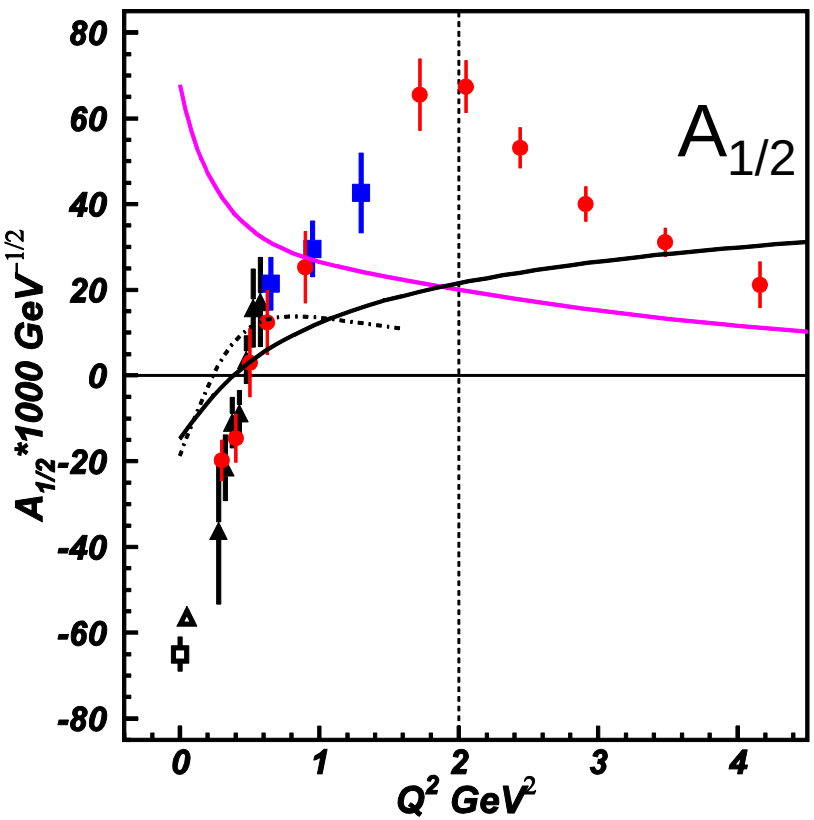
B,Julia-Diaz et al., Phys. Rev. C77, 045205 (2008)



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

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

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



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).

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

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

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

- First evaluation from QCD of quark core contribution to $P_{11}(1440)$ electrocouplings.

- Evidence for substantial contributions from meson-baryon cloud in particular at Q^2<1.0 GeV^2.

- Evaluation with vector x vector interaction and momentum dependent quark mass function are in progress.

Transition N-P_{11}(1440) form factors in LQCD

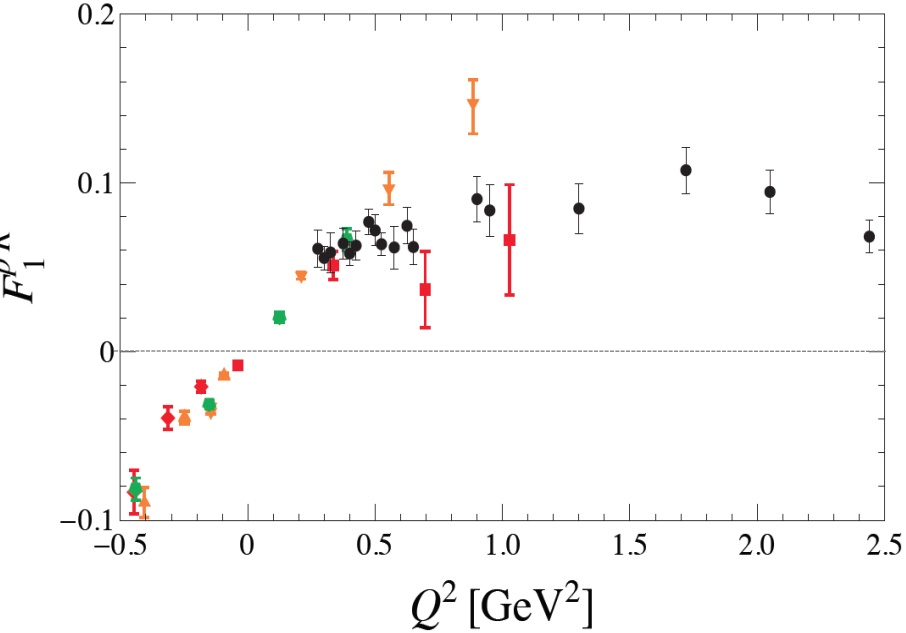
Includes the quark loops in the sea , which are critical in order to reproduce the CLAS data at Q^2<1.0 GeV^2

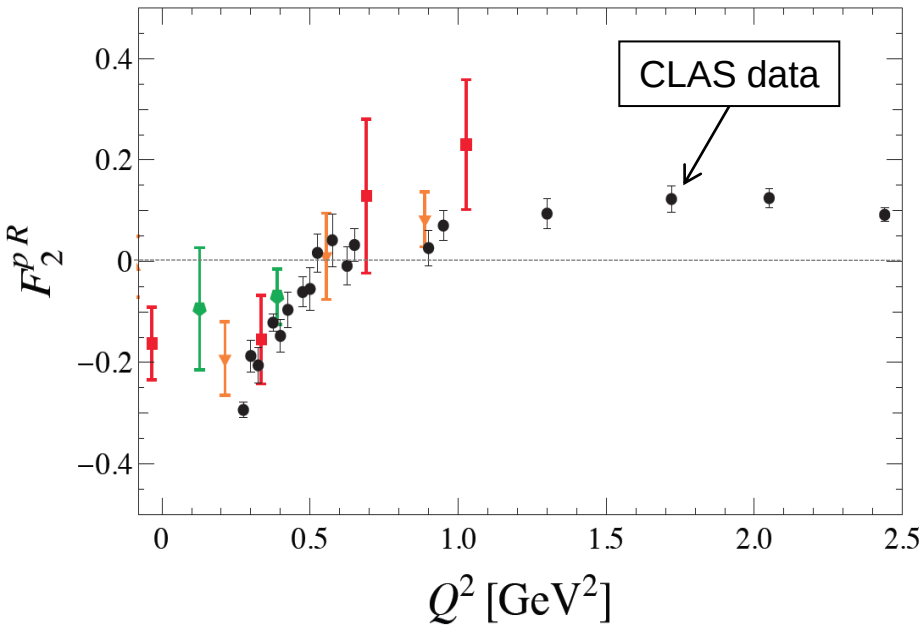
$A_{1/2}$, $S_{1/2}$ => F_1^*, F_2^*

H.W. Lin and S.D. Cohen, arXiv:1108.2528

M_π = 390, 450, 875 MeV

L box =3.0, 2.5, 2.5 f

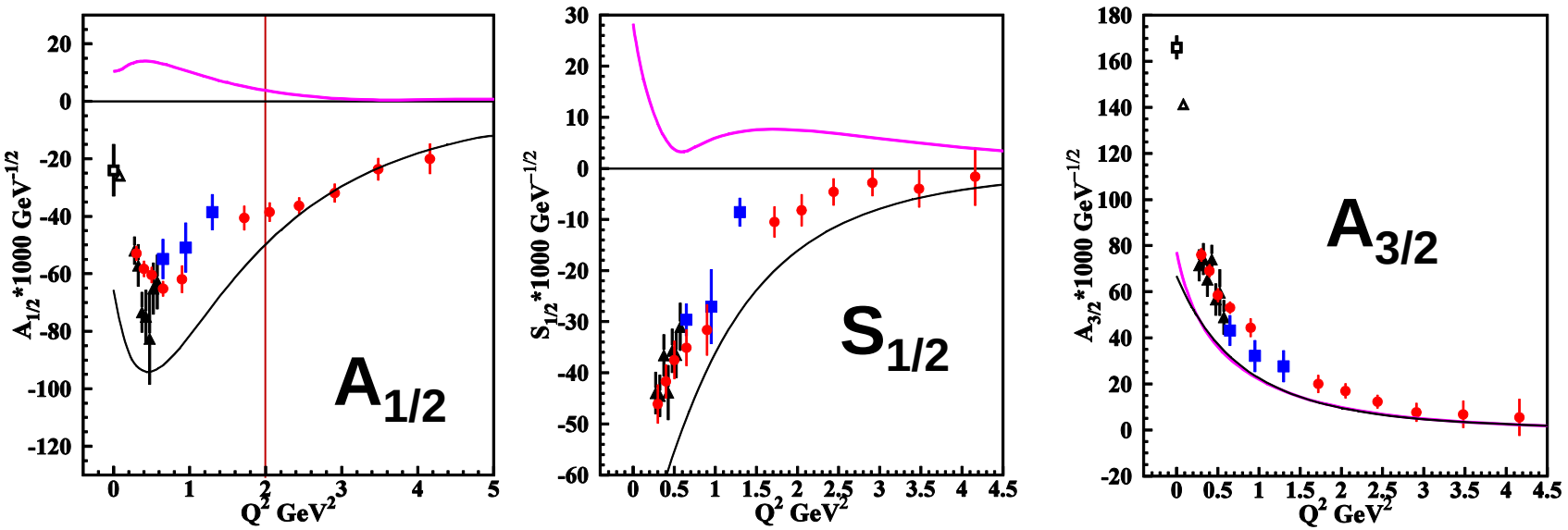




- **Exploratory LQCD results provide reasonable description of the CLAS data from the QCD Lagrangian.**

- **Prospects for LQCD evaluation with improved projection operators, approaching physical mp in the box of appropriate size.**

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



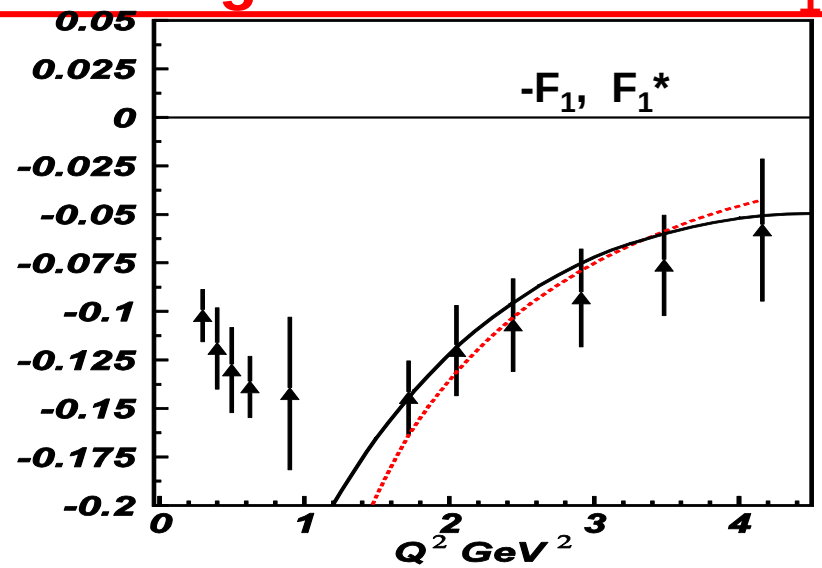
MB dressing abs val. (EBAC)

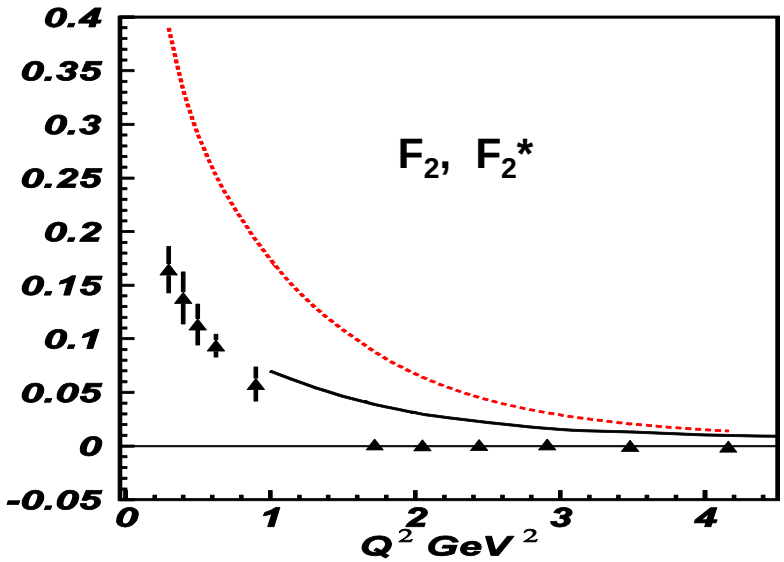
M.Giannini/E.Santopinto hCQM, Eur. Phys. J. A1, 307 (1998).

- a reasonable agreement between the results from $N\pi$ 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.

Evidence for chiral symmetry breaking from Q^2-evolution of the ground state and $S_{11}(1535)$ parity partner form factors





In chiral symmetry limit:

$$-F_1(Q^2) = (-Q^2)G_1(Q^2) = F_1^*(Q^2);$$

$$F_2(Q^2) = -\frac{(M+m)m}{\kappa}G_2(Q^2) = F_2^*(Q^2);$$

$1/2+ \to 1/2-$ transition current :

$$J_\mu = (-Q^2\gamma_\mu - q_\nu\gamma^\nu q_\mu)G_1(Q^2) - \frac{1}{2}(M+m)\, i\,\sigma^{\mu\nu}q_\nu G_2(Q^2)$$

M,m are $S_{11}(1535)$ and proton masses, k= 1.79

F_1^*, F_2^* $p \to S_{11}(1535)$ form factors from the CLAS data

parameterization of elastic Dirac F_1 and Pauli F_2 form factors

Evaluation of F_1^* and F_2^* starting from QCD within the framework of Light Cone Sum Rule & LQCD.
V.Braun et al., Phys. Rev. Lett., 103, 072001 (2009) .
Update: LCSR at NLO is in progress J.Rohrwild, priv. com.

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

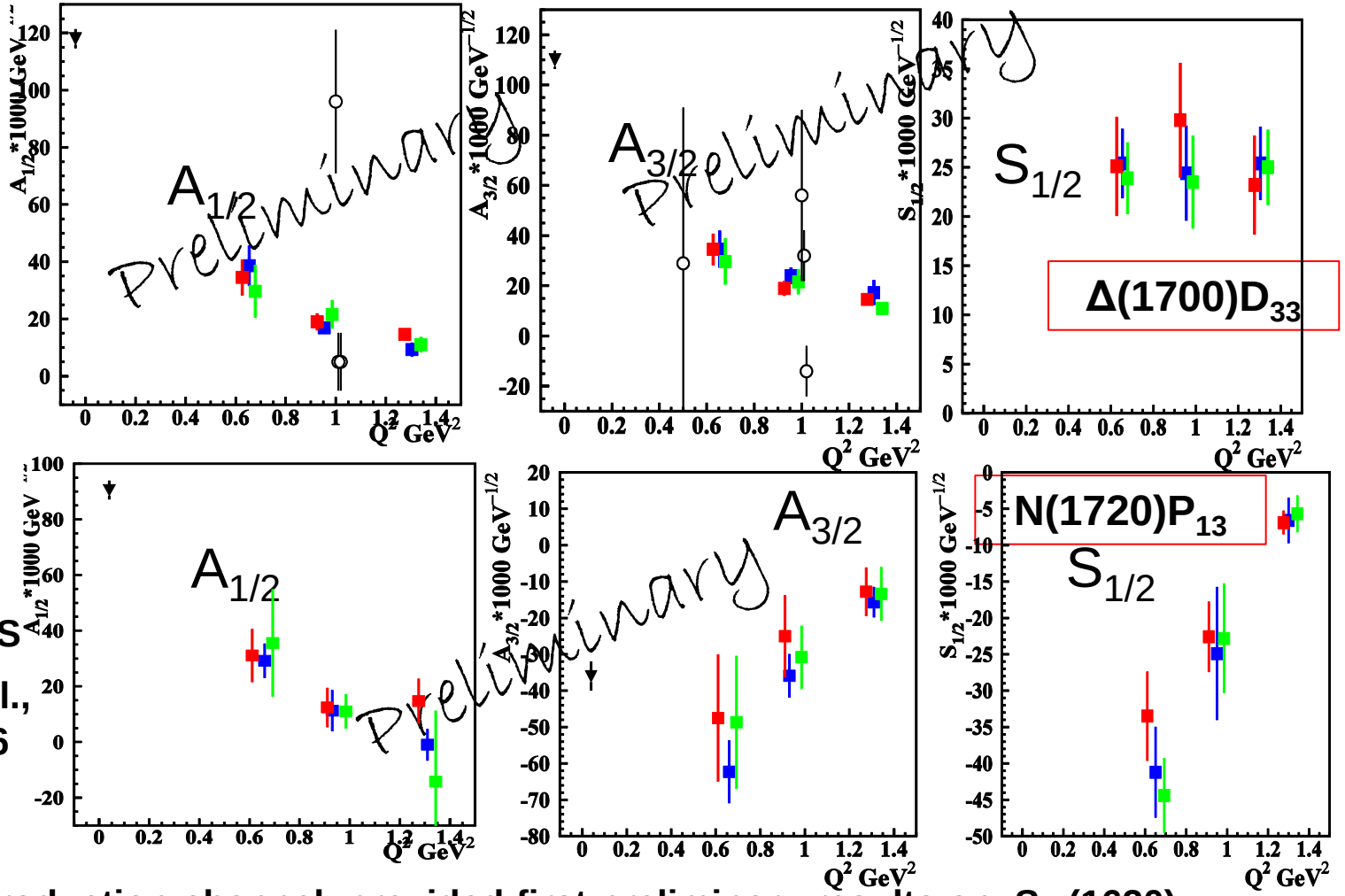
Nπ world

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

Nππ CLAS from independent fits of 3 W-intervals

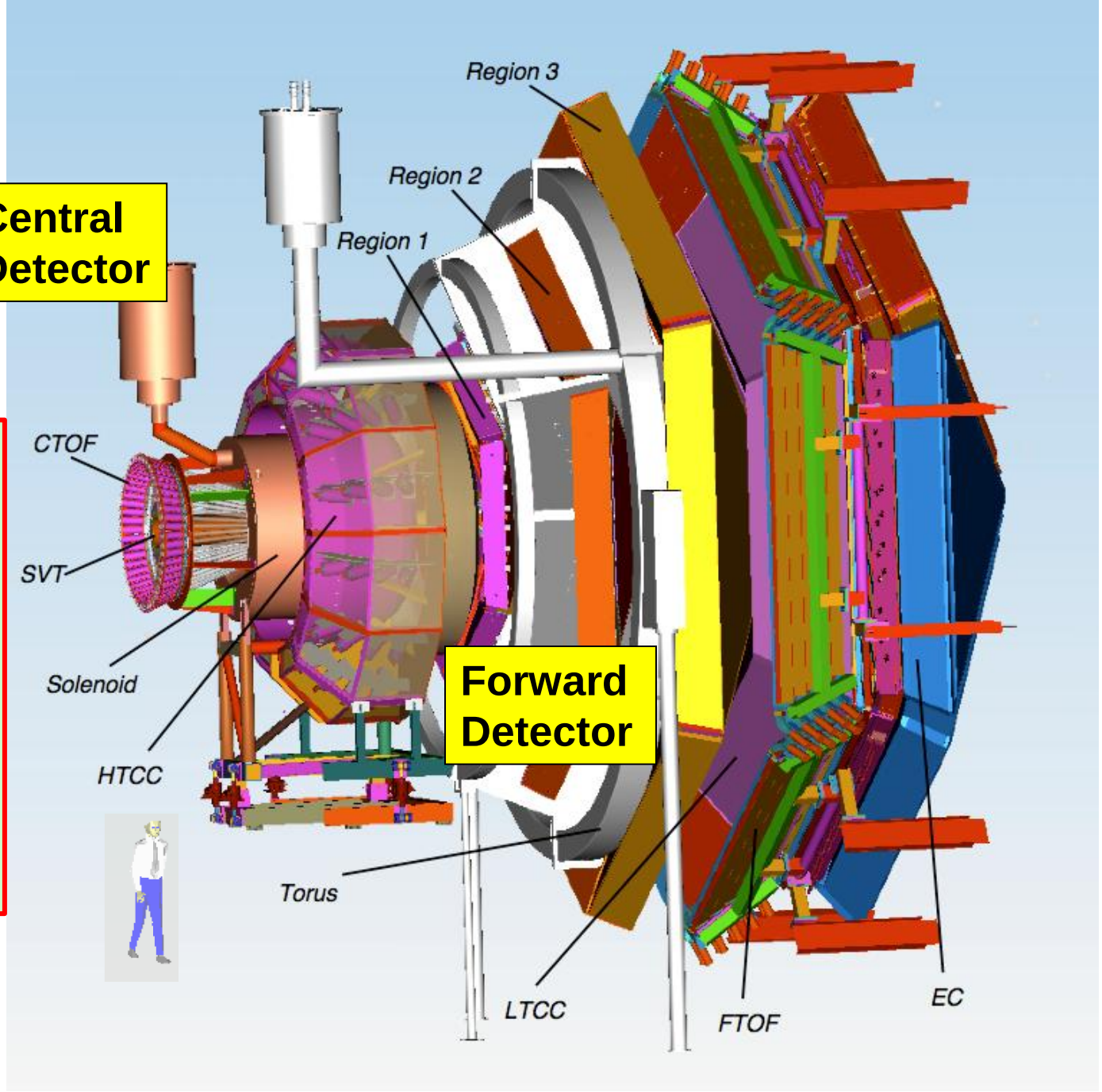
Nπ Q^2=0, CLAS

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 GeV².**

CLAS12



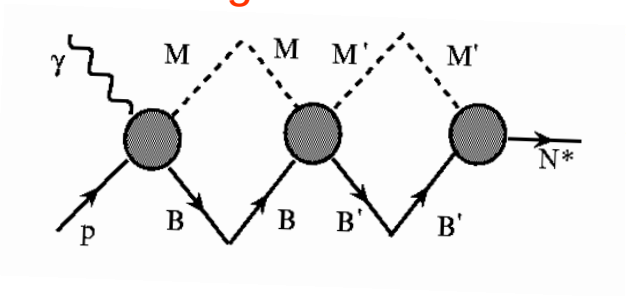
CLAS12 **supports a broad program in hadronic physics.**

Plans to study excited baryons and mesons:

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

$\gamma_v NN^*$ Electrocouplings: A Unique Window into the Quark Structure

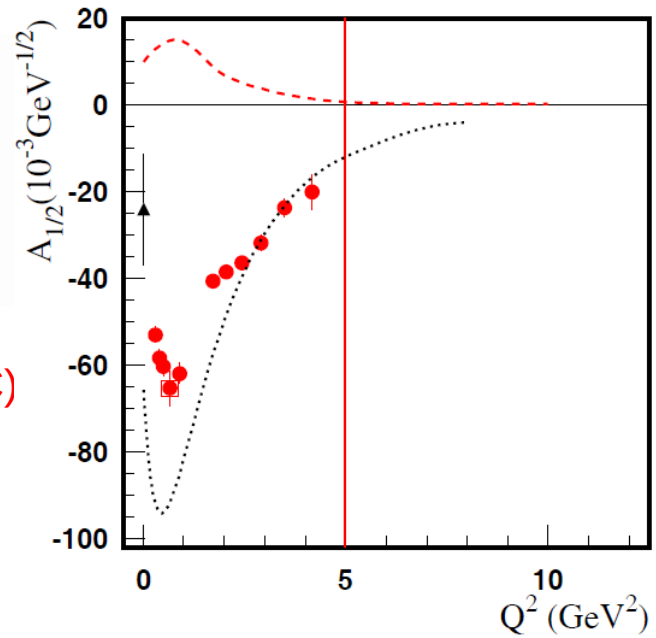
Meson-Baryon Dressing



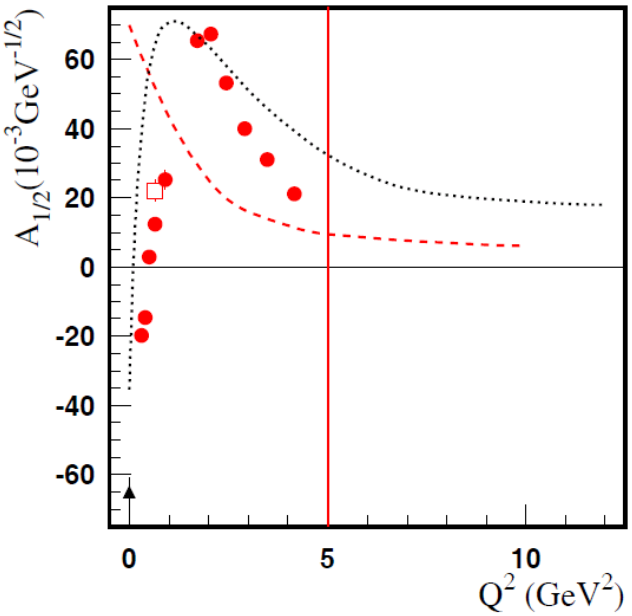
- - - absolute meson-baryon cloud amplitudes (EBAC)

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

$D_{13}(1520)$



$P_{11}(1440)$



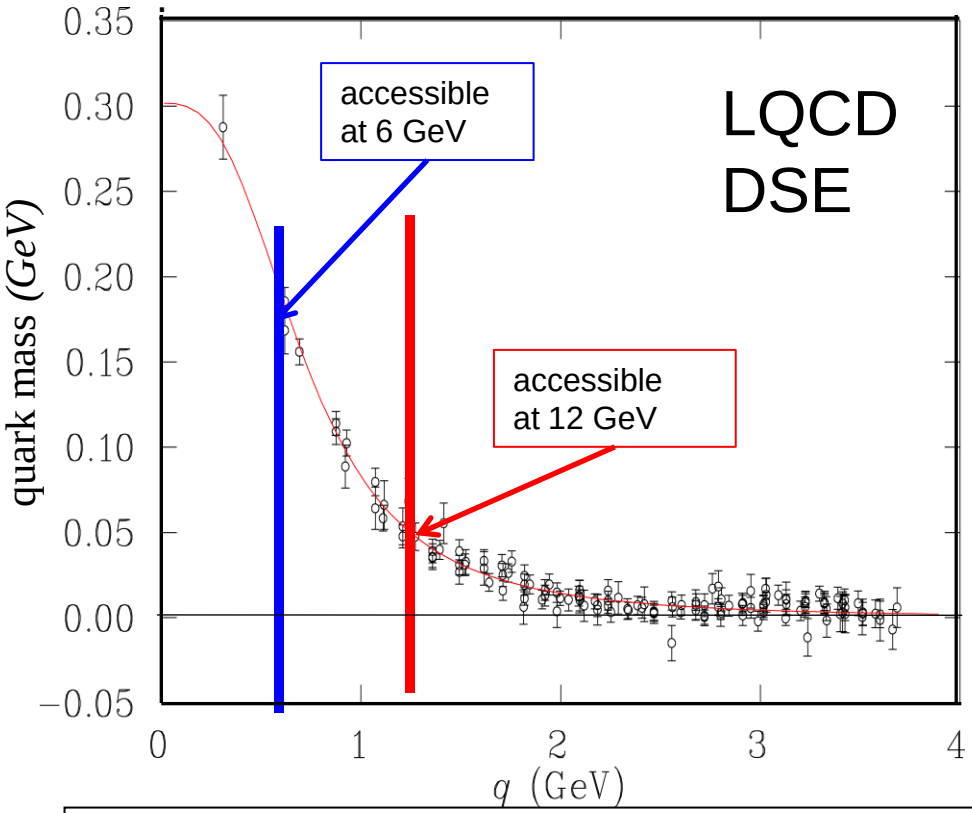
CLAS: $N\pi$ ● and $N\pi/N\pi\pi$ combined ⊞

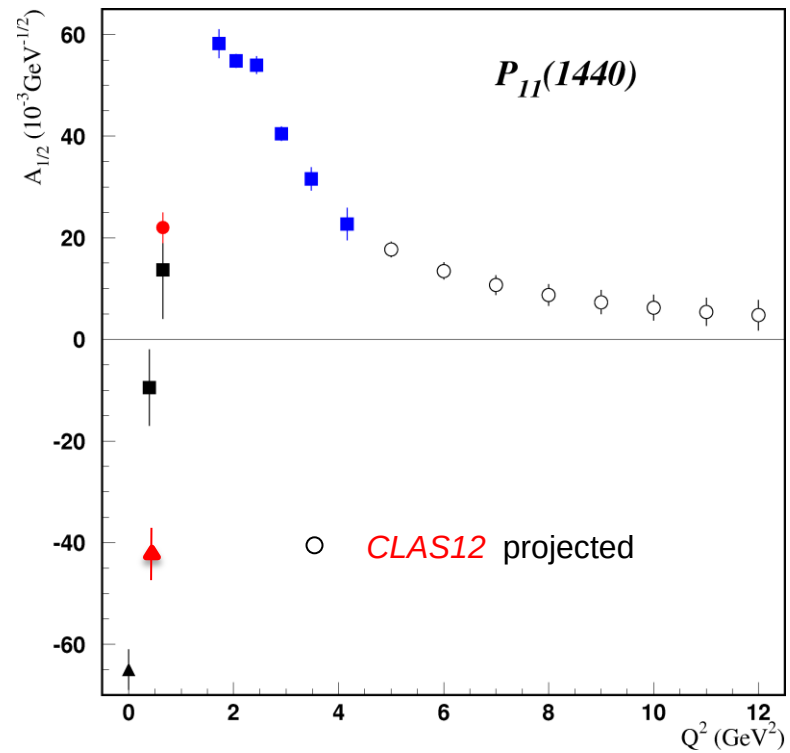
Data on $\gamma_v NN^*$ electrocouplings from E12-09-003 experiment ($Q^2 > 5$ GeV^2) will afford for the first time direct access to the non-perturbative strong interaction among dressed quarks, their emergence from QCD, and the subsequent N* formation.

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.

$\gamma_v NN^*$ 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

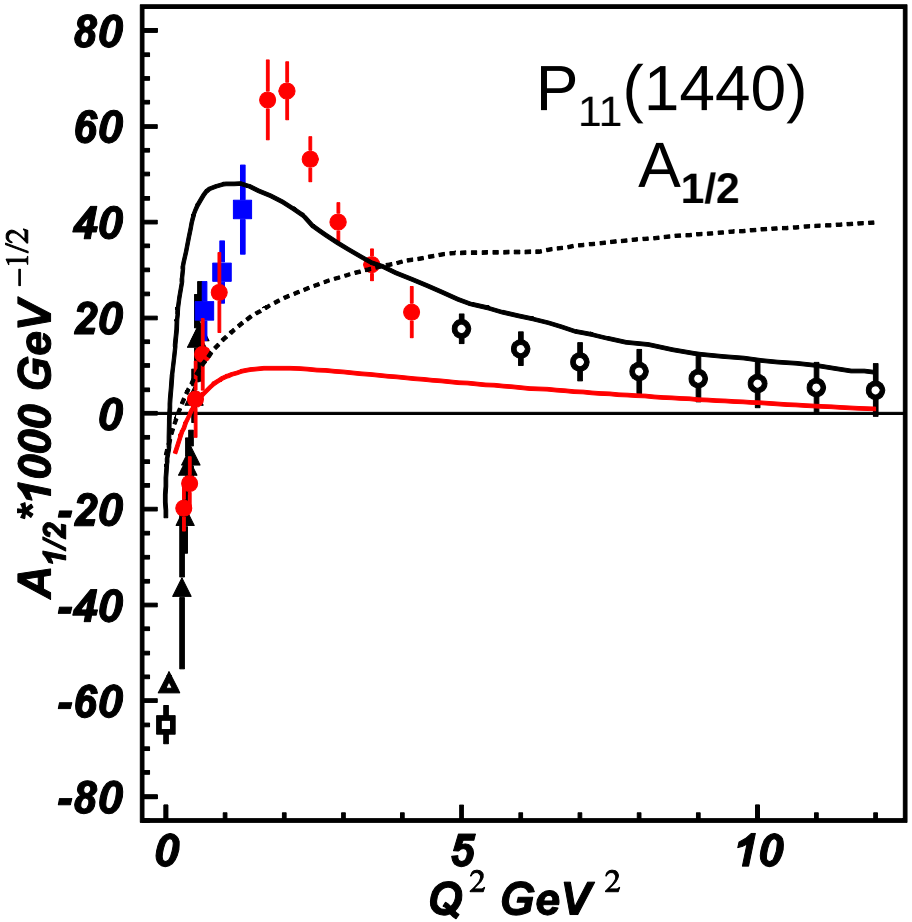
CLAS12 projected

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).

DSE with contact qq-interaction and momentum independent mass function

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



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

Conclusions and outlook

- Data on $\gamma_v NN^*$ electrocpouplings of most 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 from single meson and at Q^2<1.5 GeV^2 from double pion electroproduction channels. The files with numerical results can be requested from V.Mokeev (mokeev@jlab.org).

- The CLAS results on $\gamma_v NN^*$ electrocpouplings offer new opportunity for hadron structure theory to explore how non-perturbative strong interaction generate excited proton states of different quantum numbers

- In the future (few years time scale):
- - $\gamma_v NN^*$ electrocpoupling of N* states with M>1.6 GeV will become available from $N\pi$ channels;

  - $\gamma_v NN^*$ electrocpoupling of most excited proton states in mass range up to 2.0 GeV and at photon virtualities up to 5.0 GeV^2 will become available from analysis of $\pi^+\pi^-p$ electroproduction ;

Conclusions and outlook

- contributions of $\pi^-\Delta^{++}$, $\pi^+\Delta^0$, $\pi^+D_{13}(1520)$, $\pi^+F_{15}(1685)$ and ρp channels to nine 1-fold $\pi^+\pi^-p$ cross sections can be obtained from the CLAS data in DIS area ($2.0<W<3.0$ GeV, $2.0<Q^2<5.0$ GeV^2), if they can be used for extraction of transition $p\rightarrow N^*$ GPD's and/or for extending our knowledge on diagonal GPD's from ρp exclusive electroproduction;

-two-body $\pi^-\Delta^{++}$, $\pi^+\Delta^0$, $\pi^+D_{13}(1520)$, $\pi^+F_{15}(1685)$ and ρp cross sections in terms of CM angular distributions at different masses of unstable hadron can be obtained from $\pi^+\pi^-p$ cross sections for subsequent extraction of these channel amplitudes, employing amplitude analysis methods;

-resonant contributions to meson electroproduction amplitudes can be provided for the studies of global and local duality.

•The CLAS12 detector is the only foreseen worldwide facility, which will be capable to explore N* electrocouplings at largest photon virtualities ever achieved $5.0<Q^2<12$ GeV^2. For the first time, we will be able to explore regime of quark core dominance, probe momentum dependence of dressed quark mass function in the transition from confinement to pQCD regime and to explore how >98 % of hadron mass in the Universe are generated via dynamical chiral symmetry breaking and how confinement in baryons emerges from QCD.

Back -up

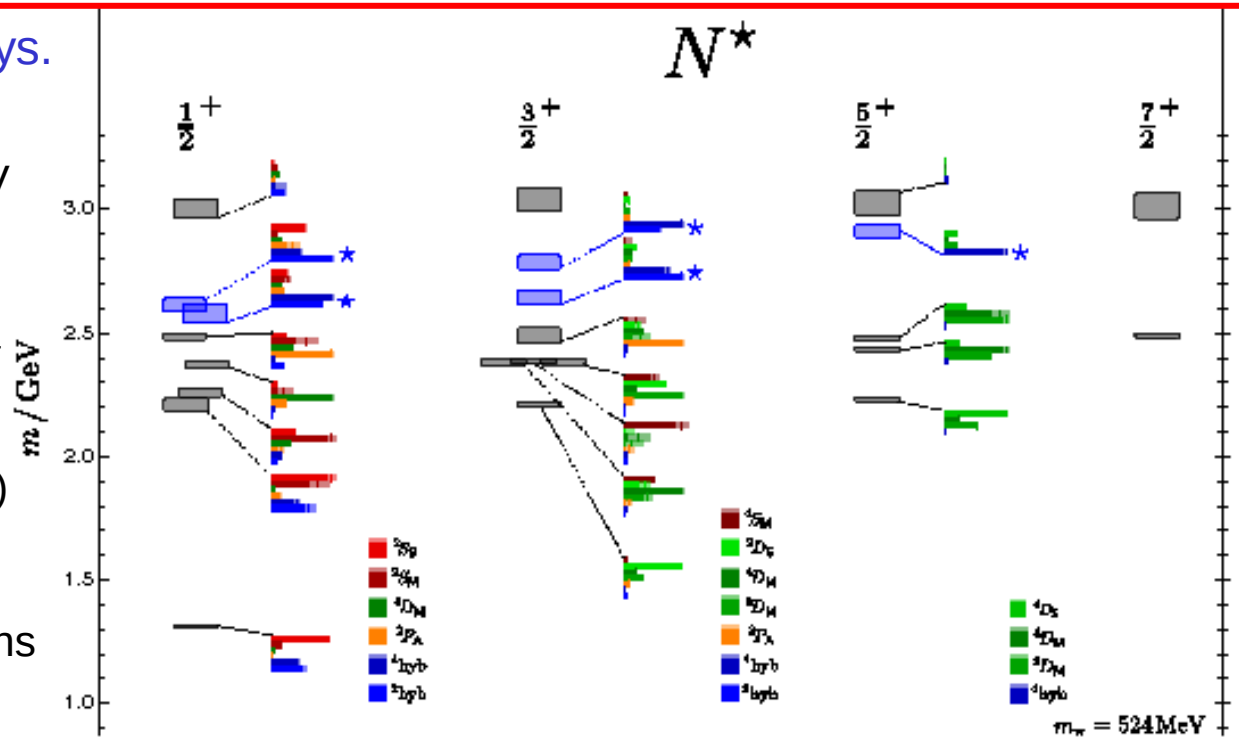
Impact of the Recent LQCD studies of N* Spectrum and Structure on the N* Program with CLAS/CLAS12

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.**

Evidence for new N* states and couplings

State N((mass) J^P	PDG 2010	PDG 2012	KΛ	KΣ	Nγ
N(1710)1/2$^+$	*** (not seen in GW analysis)	***	***	**	***
N(1880)1/2$^+$		**	**	*	**
N(1895)1/2$^-$		**	**	*	***
N(1900)3/2$^+$	**	***	***	**	***
N(1875)3/2$^-$		***	***	**	***
N(2150)3/2$^-$		**	**		**
N(2000)5/2$^+$	*	***	**	*	**
N(2060)5/2$^-$		***		**	***

Bonn-Gatchina Analysis – A.V. Anisovich et al., EPJ A48, 15 (2012)
Strong impact from the CLAS KY photoproduction data on the signala from new states
New states still need to be confirmed

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).

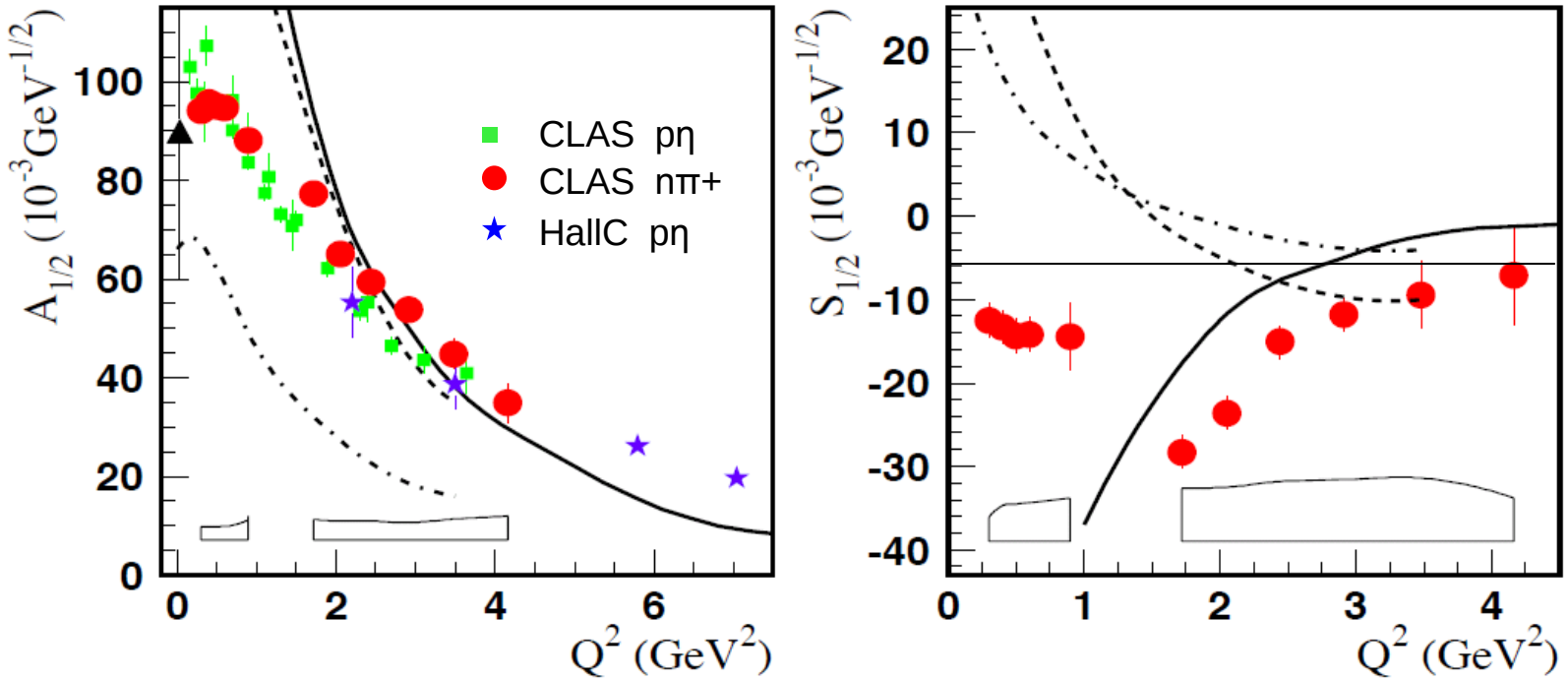
Summary of the CLAS data on KY electroproduction off protons

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/

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.

Signals from N* states in the CLAS KY electroproduction data

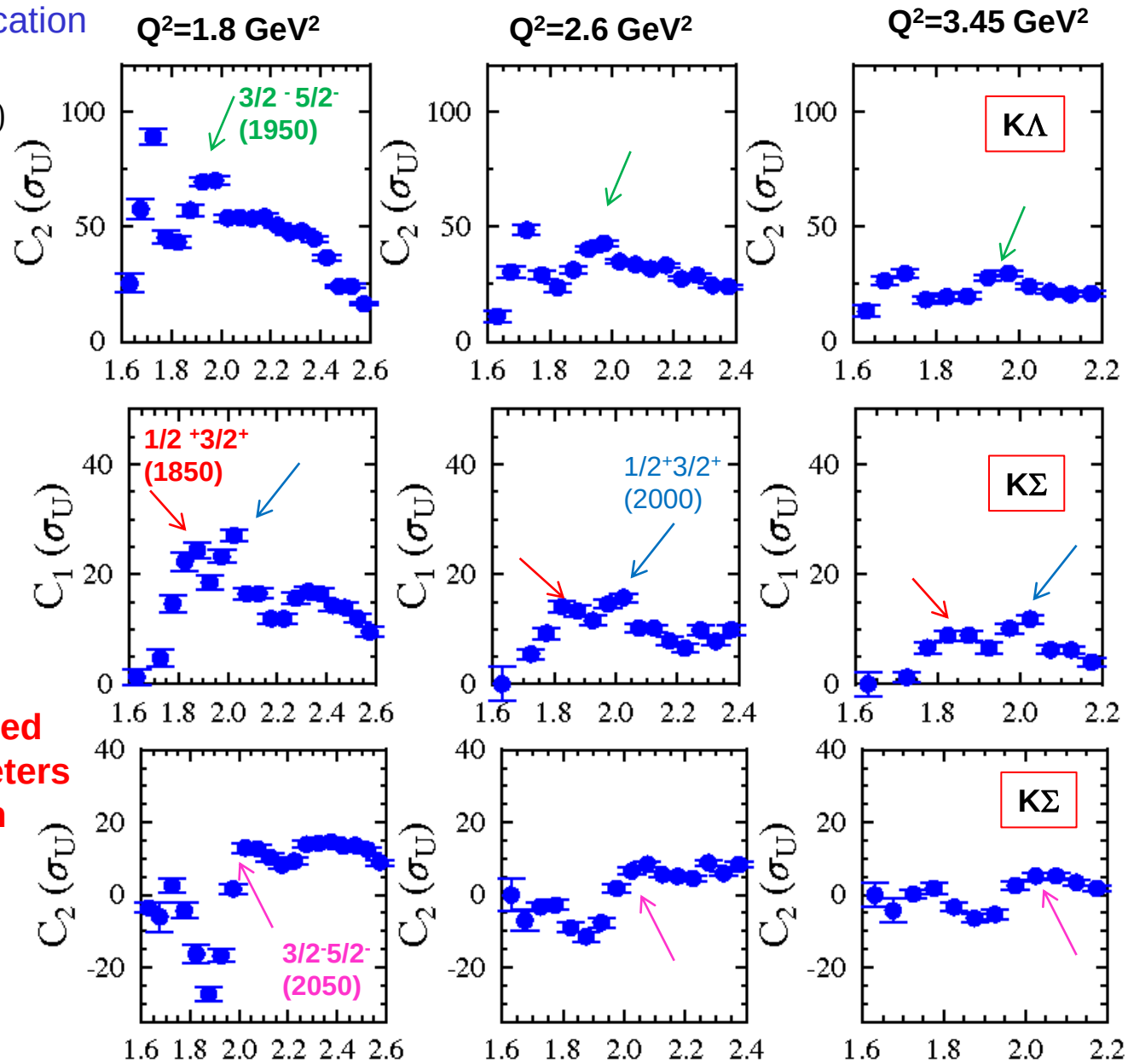
D.Carman, private communication

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

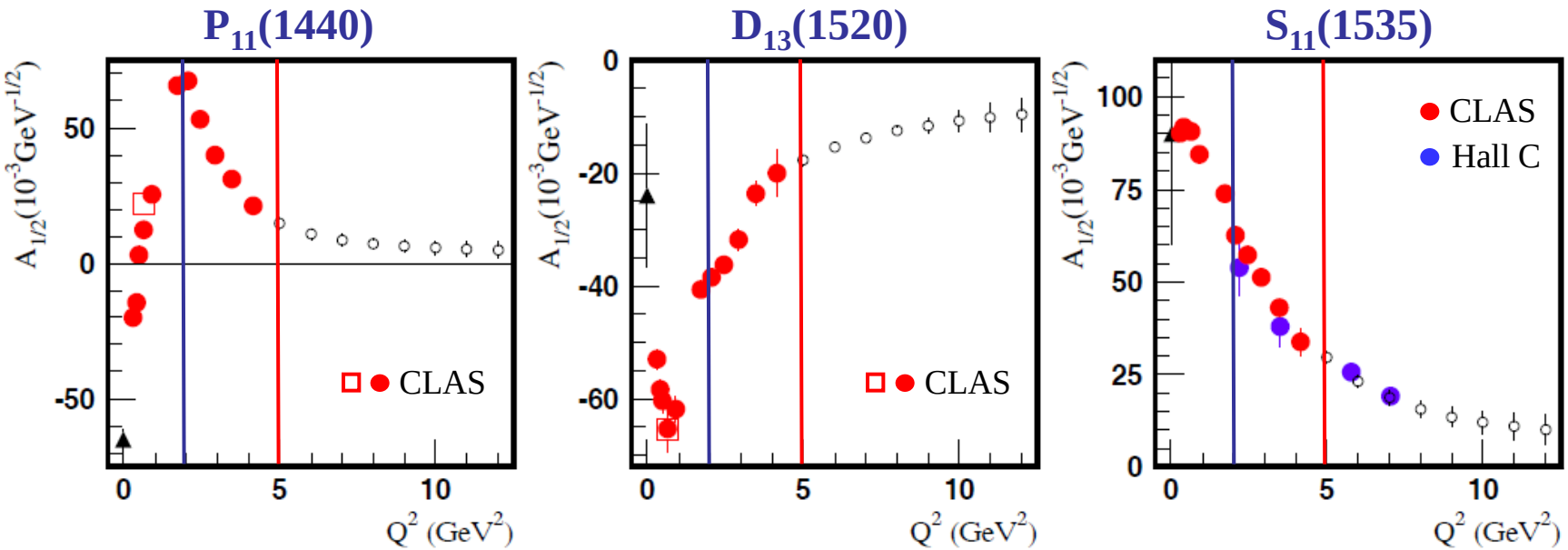
$$z = \cos(\theta_K)$$

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



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.

Reaction Models for Extraction of $\gamma_v NN^*$ Electrocoupling at Q^2>5.0 GeV^2

•All currentl reaction models for extraction of $\gamma_v NN^*$ 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 $\gamma_v NN^*$ electrocouplings from $N\pi$ 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 $\gamma_v NN^*$ 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 $N\pi$ and $N\pi\pi$ electroproduction data

For discussion

- The contribution of $\pi^-\Delta^{++}$, $\pi^+\Delta^0$, $\pi^+D_{13}(1520)$, $\pi^+F_{15}(1685)$ and ρp channels to nine 1-fold $\pi^+\pi^-p$ cross sections (kind of shown in the slide #16) can be obtained in the future at $2.0<W<3.0$ GeV and $2.0<Q^2<5.0$ GeV^2

  Would it be possible to use these results for extraction of transition $\pi\to\Delta$, $p\to D_{13}$,(1520) $p\to F_{15}$ (1685) GPD's and diagonal $p\to p$ GPD from ρp exclusive channel?

- Two-body $\pi^-\Delta^{++}$, $\pi^+\Delta^0$, $\pi^+D_{13}(1520)$, $\pi^+F_{15}(1685)$ and ρp cross section at different fixed running masses of unstable hadron can be determined from available $\pi^+\pi^-p$ cross sections. Is it possible to use "data" on these two body angular distribution for reconstruction of these channel amplitudes?