Transition Nucleon Resonance Electrocouplings from the CLAS data on $\pi^+\pi^-$p Electroproduction off Protons

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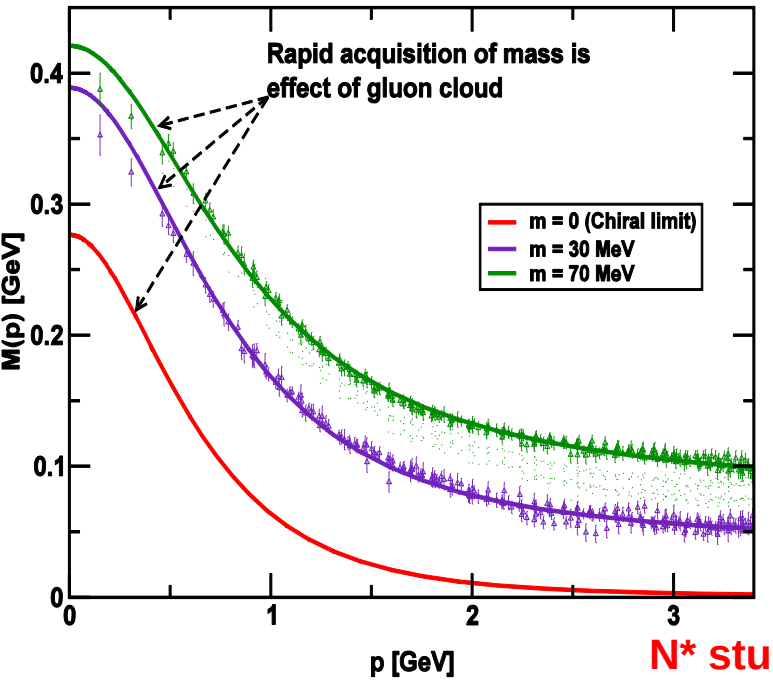
- **Introduction.**
- **JM model for evaluation of N* electrocouplings in analyzing the $\pi^+\pi^-$p electroproduction.**
- **N* electrocouplings from N$\pi\pi$ channel.**
- **Conclusions and outlook.**

The studies of N* electrocouplings: motivation & objectives

Our experimental program seeks to determine

γ_vNN* transition helicity amplitudes (electrocouplings) at photon virtualities $0.2 < Q^2 < 5.0$ GeV^2 for almost all excited proton states analyzing major Nπ & N$\pi\pi$ meson electroproduction channels combined.

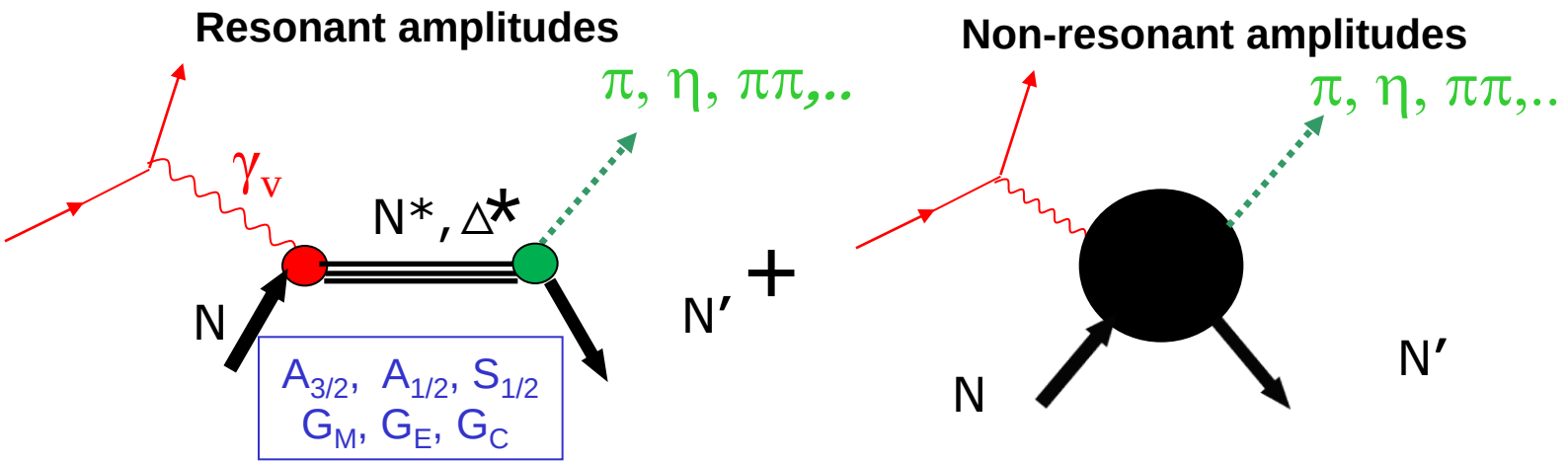
This comprehensive information allows us to:



- **pin-down active degrees of freedom in N* structure at various distances;**
- **study the non-perturbative strong interactions which are responsible for nucleon formation and their emergence from QCD;**
- **uniquely access to the origin of more than 97% of nucleon mass generated through dynamical chiral symmetry breaking, and to the behavior of the running strong coupling in the confinement regime.**

N* studies are of key importance for the exploration of non-perturbative strong interactions and quark/gluon confinement

Why is the $\pi^+\pi^-$p electroproduction channel important?



- **Nπ/N$\pi\pi$ channels are the two major contributors in N* excitation region with entirely different non-resonant amplitudes;**

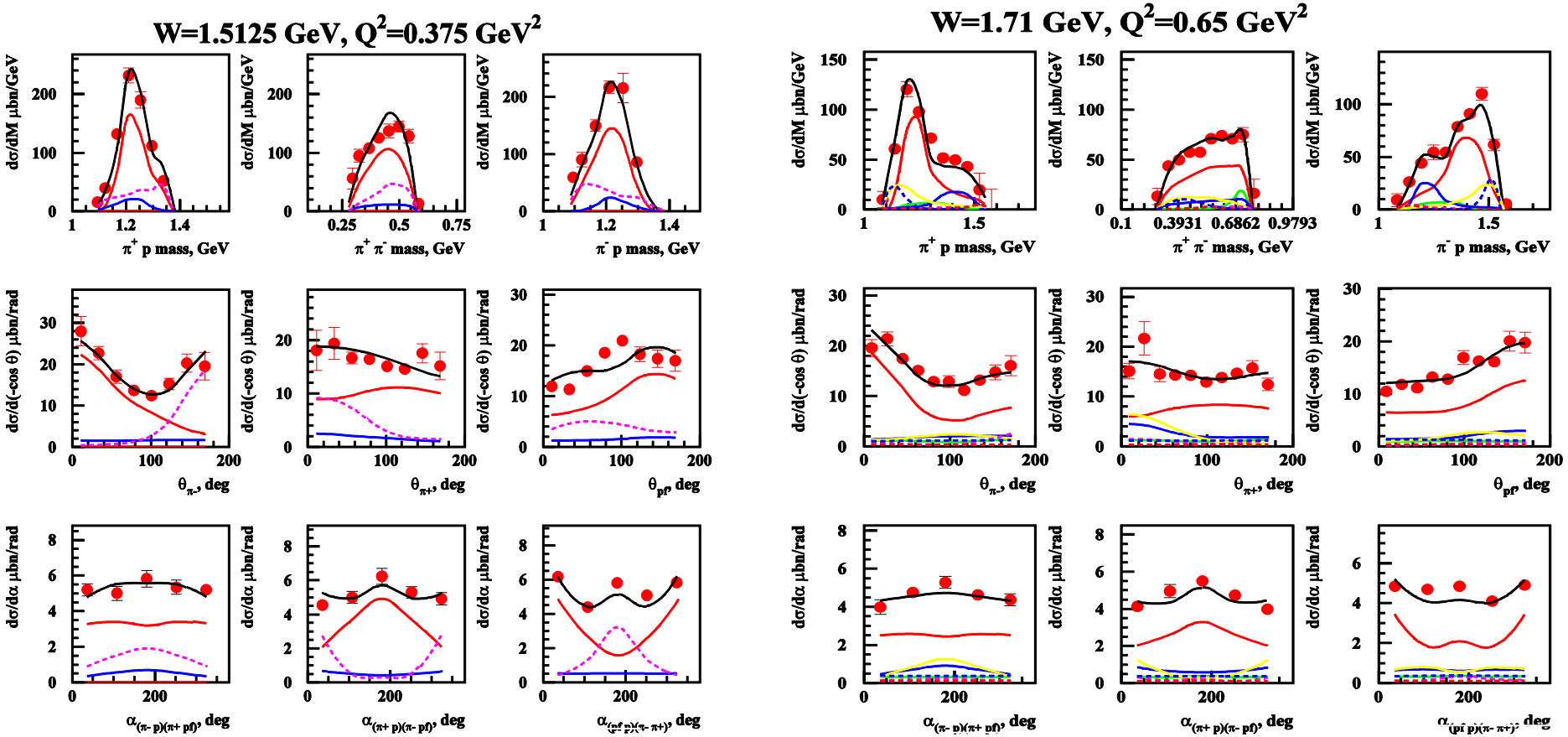
- **consistent results obtained from the analyses of Nπ and $\pi^+\pi^-$p channels give confidence that N* electrocouplings can be extracted reliably from these channels;**

- **the $\pi^+\pi^-$p electroproduction channel is of particular importance for studies of high lying N*'s (M>1.6 GeV) that preferably decay to the N$\pi\pi$ final state.**

The CLAS data on $\pi^+\pi^-p$ differential cross sections and their description within the JM model

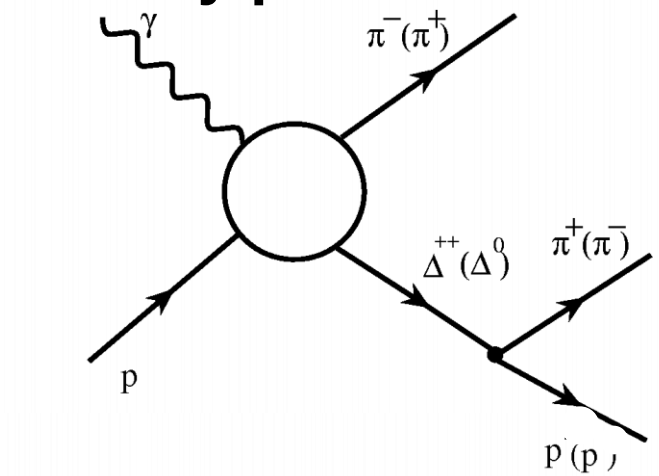
G.V.Fedotov et al, PRC 79 (2009), 015204

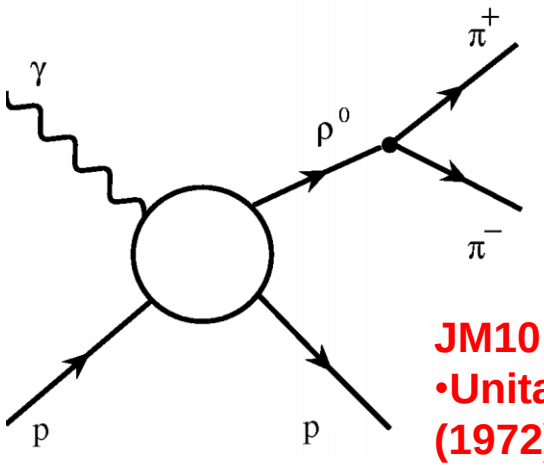
M.Ripani et al, PRL 91 (2003), 022002



JLAB-MSU meson-baryon model (JM) for Nππ electroproduction.

3-body processes:





Isobar channels included:

$\pi^-\Delta^{++}$

- **All well established N*s with πΔ decays and 3/2⁺(1720) candidate.**
- **Reggeized Born terms with effective FSI & ISI treatment .**
- **Extra πΔ contact term.**

$\rho^0 p$

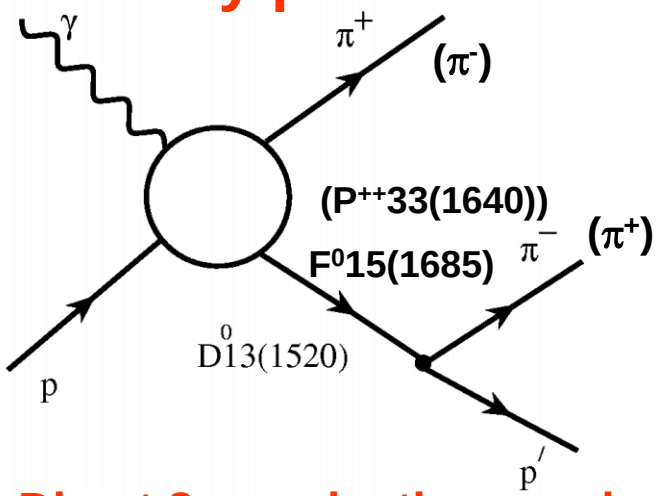
- **All well established N*s with ρp decays and 3/2⁺(1720) candidate.**
- **Diffractive ansatz for non-resonant part and ρ-line shrinkage in N* region.**

JM10 version:

- **Unitarized BW ansatz, developed based on: I.J.R.Aitchison NP A189 (1972), 417;**
- **implemented $S_{11}(1535)$ with minor Nππ decays**

continued

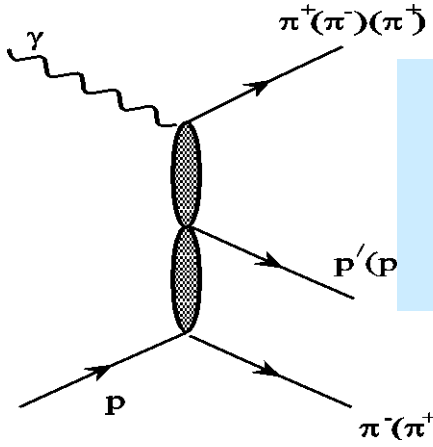
3-body processes:



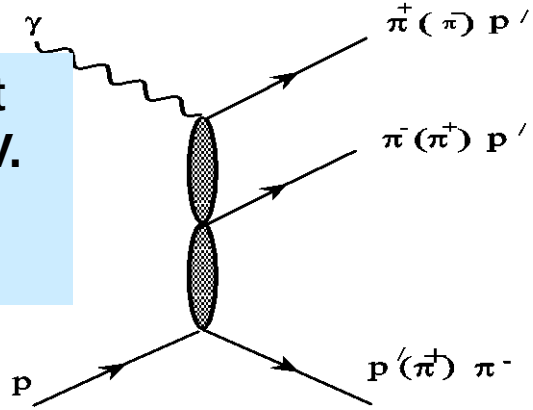
Isobar channels included:

• $\pi^+D^0_{13}(1520)$, $\pi^+F^0_{15}(1685)$, $\pi^-P^{++}_{33}(1640)$ isobar channels observed for the first time in the CLAS data at W > 1.5 GeV.

Direct 2π production required by unitarity and established for the first time in analysis of the CLAS $\pi^+\pi^-$p data

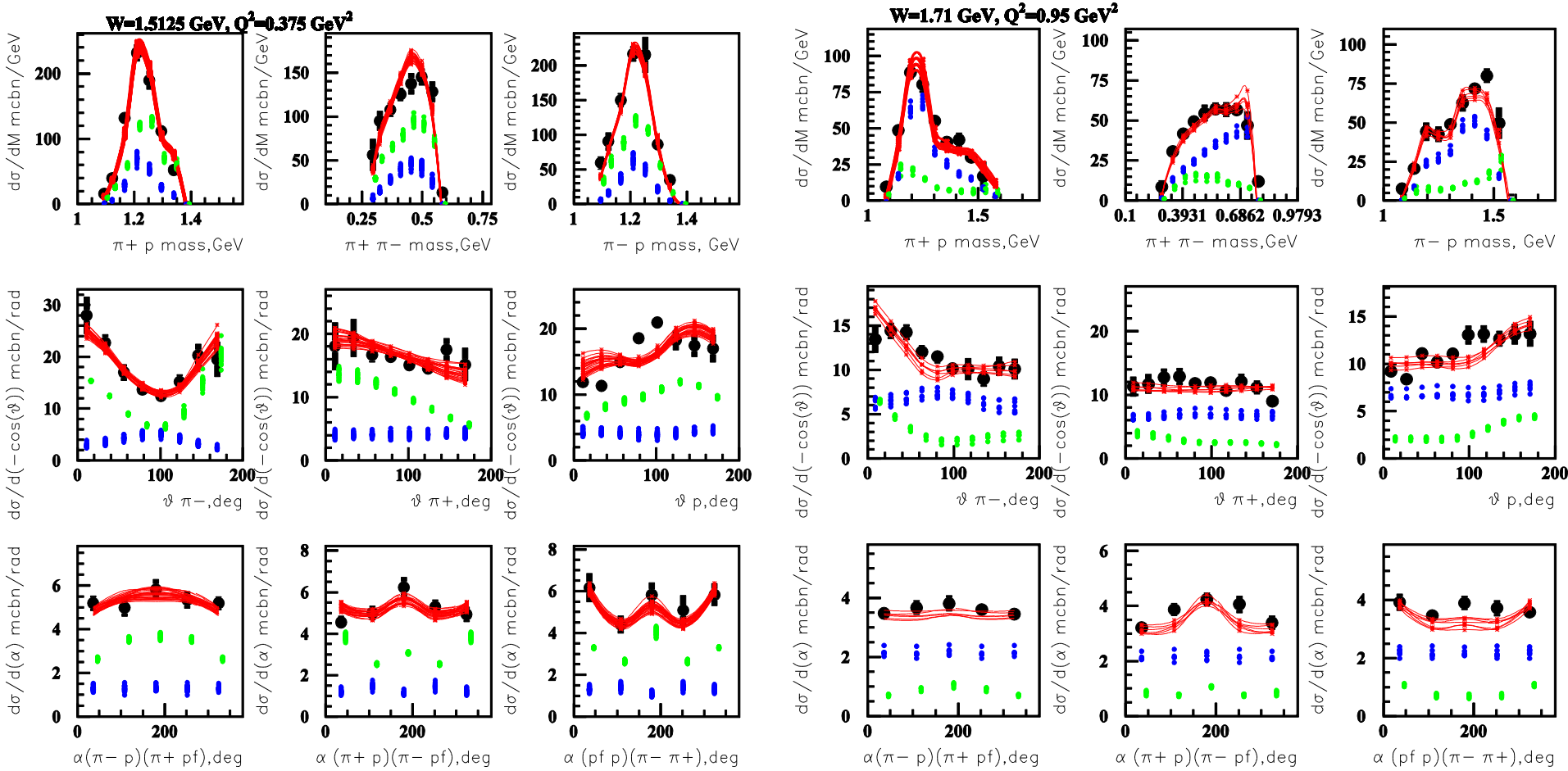


Most relevant at W<1.65 GeV. Negligible at W>1.70 GeV



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

Resonant & non-resonant parts of Nππ cross sections as determined from the CLAS data fit within the framework of JM model



full cross sections resonant part non-resonant part

$P_{11}(1440)$ electrocouplings from the CLAS data on $N\pi/N\pi\pi$ electroproduction

$N\pi\pi$ preliminary

$N\pi$ I.Aznauryan,V.Burkert, et al., PRC 80,055203 (2009).

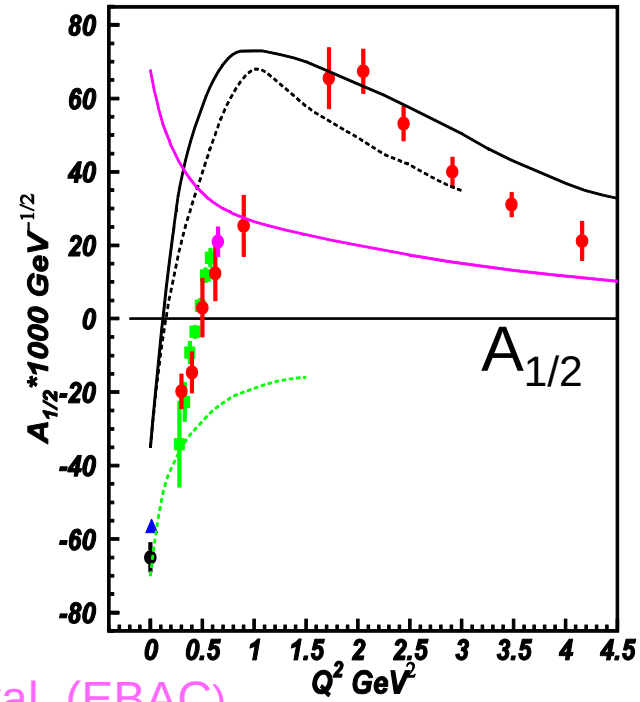
Light front models:

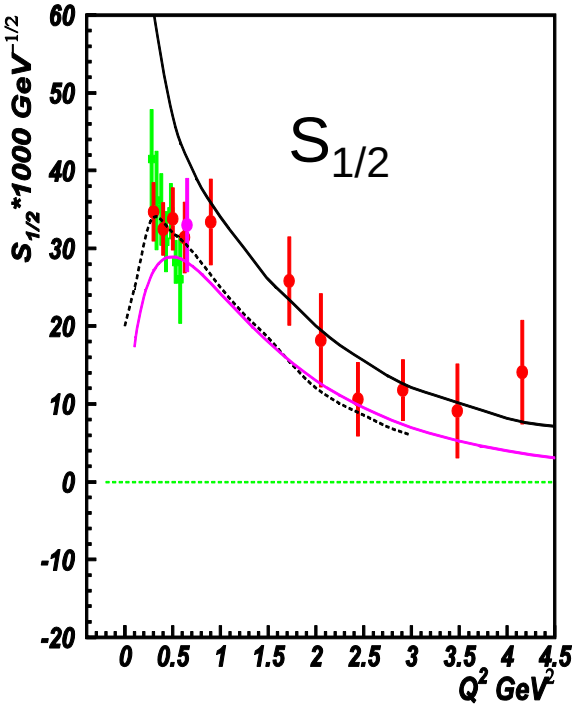
I. Aznauryan

S. Capstick

hybrid $P_{11}(1440)$

MB dressing abs val. (EBAC)





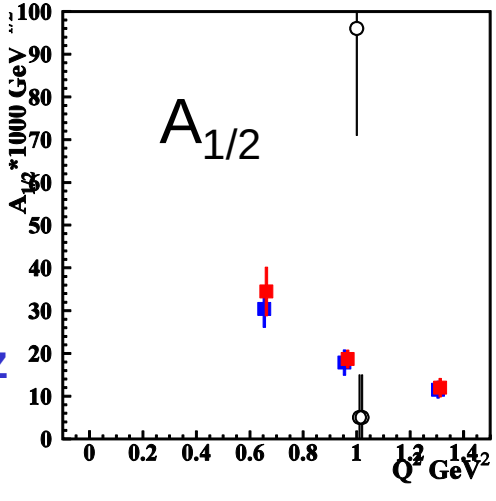
- **Good *agreement* between the electrocouplings obtained from the *$N\pi$ and $N\pi\pi$ channels*: Reliable measurement of the electrocouplings.**
- **The electrocouplings for $Q^2 > 2.0$ GeV^2 are consistent with *$P_{11}(1440)$* structure as a *3-quark radial excitation of the nucleon*. MB cloud contributions are biggest at $Q^2<1.0$ GeV^2 and gradually decrease with Q^2.**

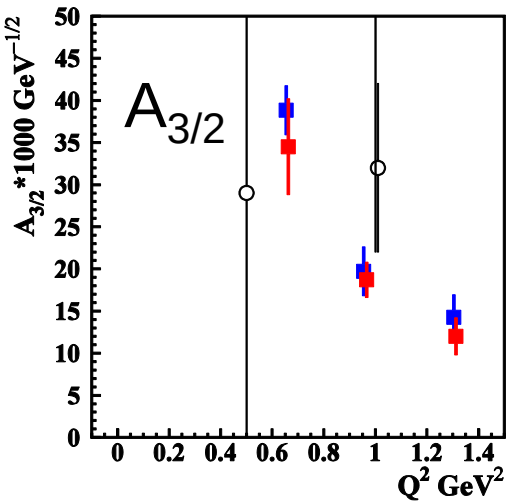
High lying resonance electrocouplings from the $\pi^+\pi^-p$ CLAS data analysis

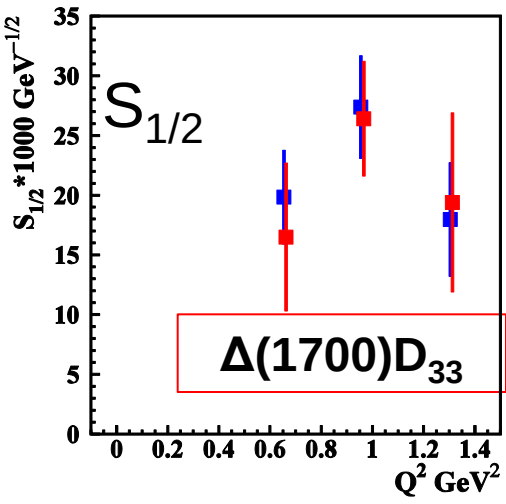
Nππ CLAS preliminary:

Unitarized BW ansatz

Regular BW ansatz

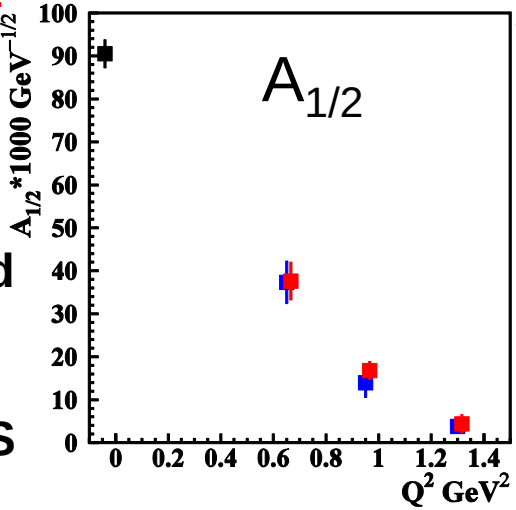


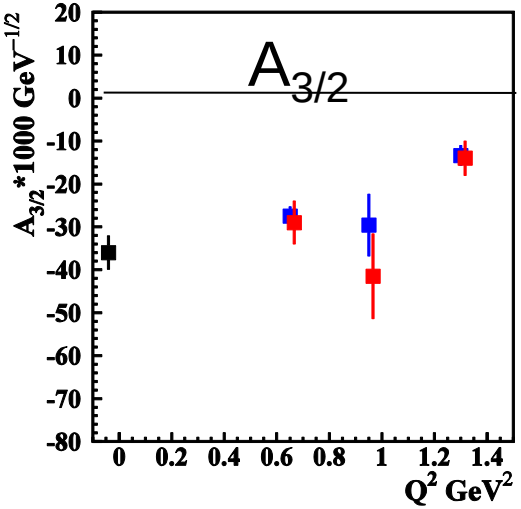


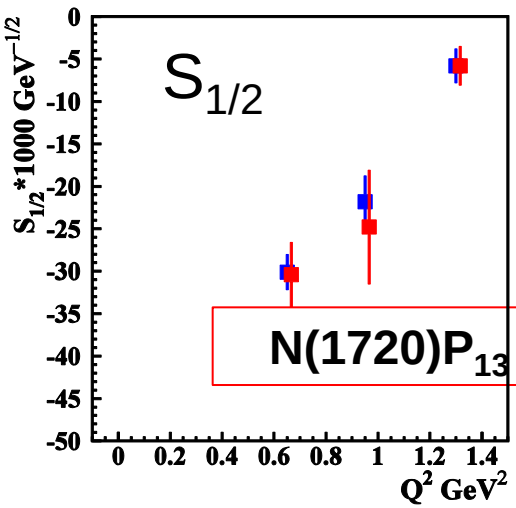


Nπ world

Nπ CLAS Q^2=0

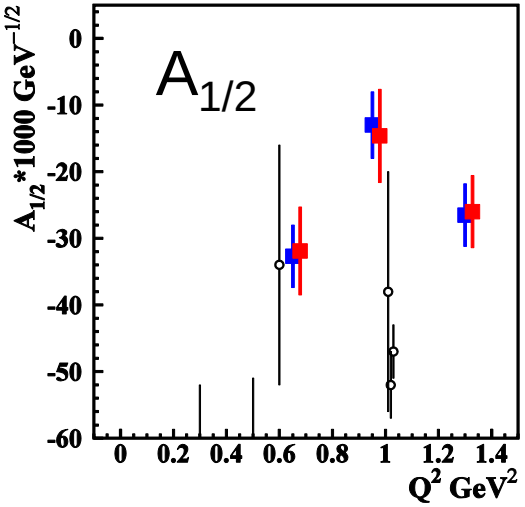


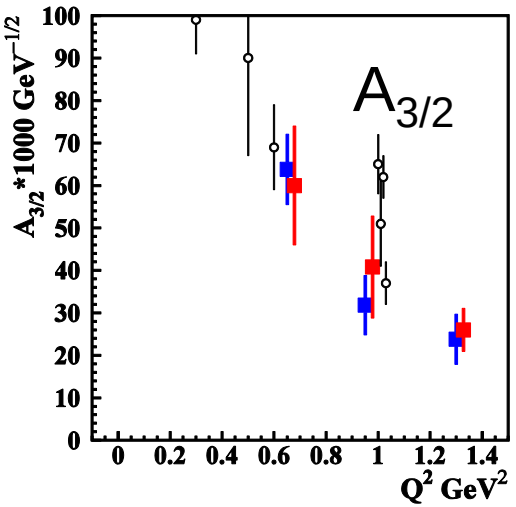


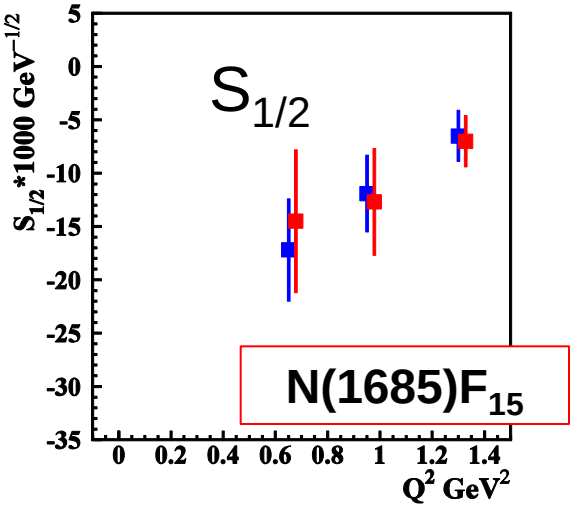


The studies of $\pi^+\pi^-p$ electroproduction are needed for reliable extraction of transition γ_vNN* electrocouplings for high lying states

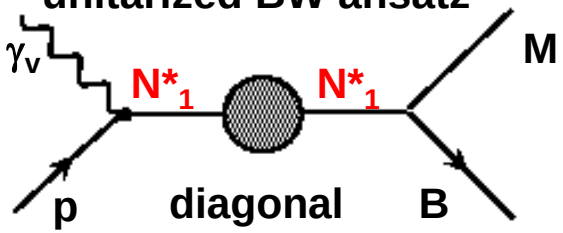
High lying resonance electrocouplings from Nππ CLAS data analysis

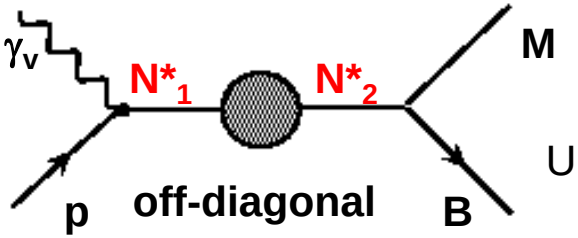


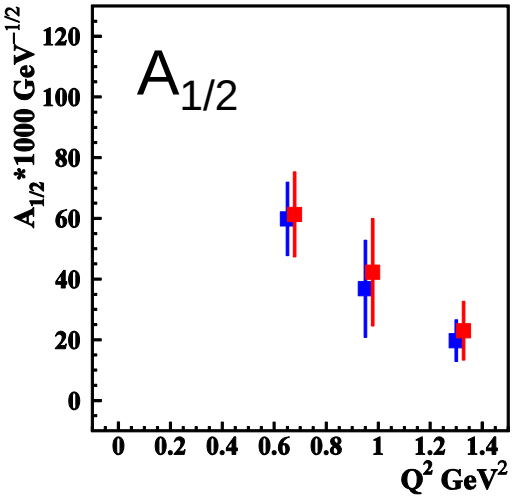


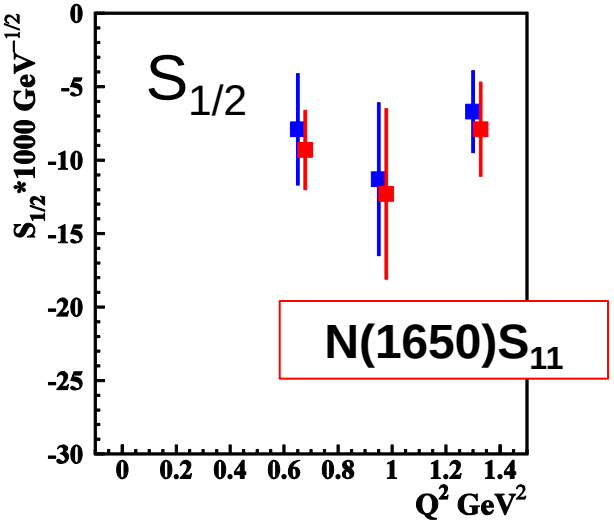


The amplitudes of unitarized BW ansatz









Unitarization of full BW amplitudes was achieved accounting for all interactions between N*'s in dressed resonant propagator

N* hadronic parameters derived from the CLAS $\pi^+\pi^-p$ data fit

$P_{13}(1720)$

	Γ_{tot}, MeV	$\Gamma_{\pi\Delta}$, MeV	$\Gamma_{\rho p}$, MeV	M,GeV
Regular BW ansatz	135±12	1.53±1.05	114±12	1.743±0.006
Unitarized BW anstaz	113±3.4	10.9±1.40	82.9±3.26	1.744±0.007

$3/2^+(1720)$ candidate state

	Γ_{tot}, MeV	$\Gamma_{\pi\Delta}$, MeV	$\Gamma_{\rho p}$, MeV	M,GeV
Regular BW ansatz	86±5	44±5.5	6.25±1.62	1.727±0.003
Unitarized BW anstaz after improvements	107±12	61±12	0.63±0.21	1.725±0.006

Unitarization of BW ansatz affects substantially N* hadronic decay parameters, while the impact on γ_vNN* electrocouplings is almost negligible

Conclusions and outlook

- All essential $\pi^+\pi^-p$ electroproduction mechanisms were established in analysis of the CLAS data within the framework of JM model at $W<1.8$ GeV and $0.25<Q^2<1.5$ GeV^2. Good data description was achieved allowing us to isolate resonant contributions.

- $\gamma_v NN^*$ transition electrocouplings for almost all N*'s with masses <1.8 GeV were determined for the first time from $\pi^+\pi^-p$ electroproduction data at $0.25 < Q^2<1.5$ GeV^2

- The consistent results on $P_{11}(1440)$ and $D_{13}(1520)$ electrocouplings, extracted from dominant $N\pi$ and $\pi^+\pi^-p$ channels, strongly indicate a reliable electrocoupling measure. The studies of $\pi^+\pi^-p$ electroproduction off protons are of particular importance for evaluation of electrocouplings for high lying N* (M>1.6 GeV), that preferably decay to the $N\pi\pi$ final states.

- CLAS data on electrocouplings of almost all N*'s in the mass range M <1.8 GeV for the first time open up an opportunity:

  a) to explore the role of meson-baryon and quark degrees of freedom in structure of various resonances and evolution of these contributions with distance;

  b) to study the non-perturbative interactions of dressed quarks that create quark core in N*'s of various quantum numbers.

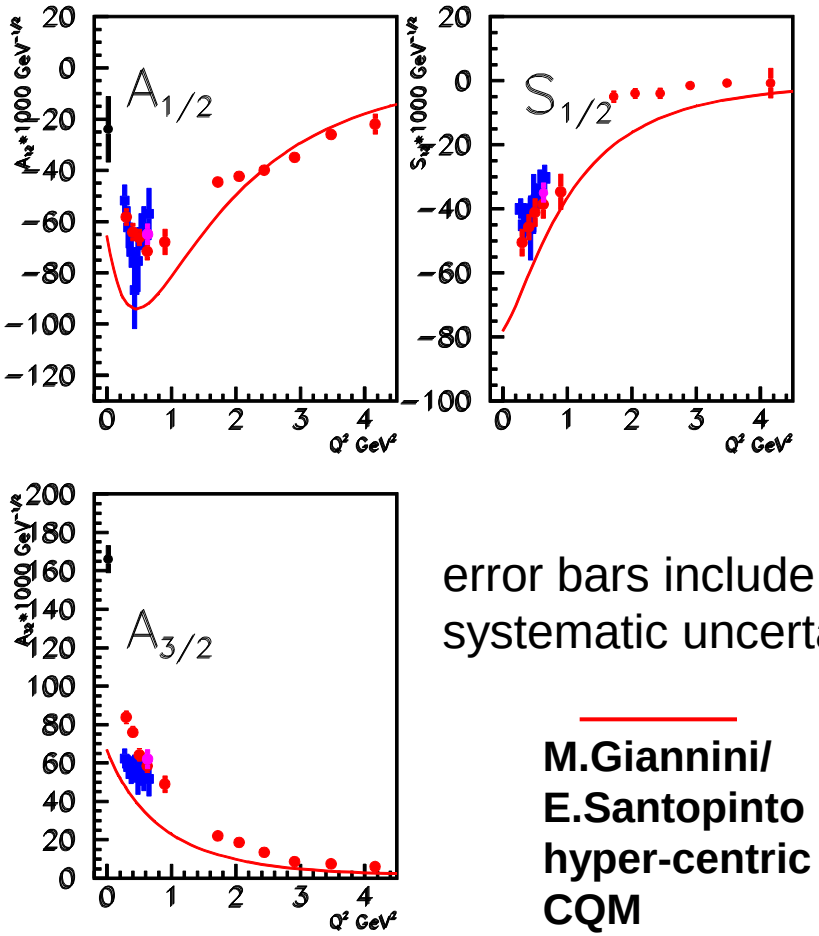
  Successful theoretical Interpretation of our data will marks essential step toward understanding of non-perturbative strong interactions.

- New CLAS data on $\pi^+\pi^-p$ electroproduction will allow us to extend the studies of N* electrocouplings toward photon virtualities $2.0<Q^2<5.0$ GeV^2 and to improve our knowledge of non-resonant amplitudes, analyzing 2 fold differential $\pi^+\pi^-p$ photoproduction cross sections that will be available for the first time.

Back-up

$D_{13}(1520)$ electrocouplings from the CLAS data on $N\pi/N\pi\pi$ electroproduction

- **electrocouplings as determined from the $N\pi$ & $N\pi\pi$ channels are in good agreement overall**
- ***but* the apparent discrepancies for the $A_{3/2}$ amplitude at $Q^2 < 0.4$ GeV^2 will be further investigated in a combined $N\pi/N\pi\pi$ analysis**
- **hypercentric Consituent Quark Model calculations reasonably describe electrocouplings at $Q^2>2.5$ GeV^2, suggesting that the 3-quark component is the primary contribution to the structure of this state at high Q^2.**

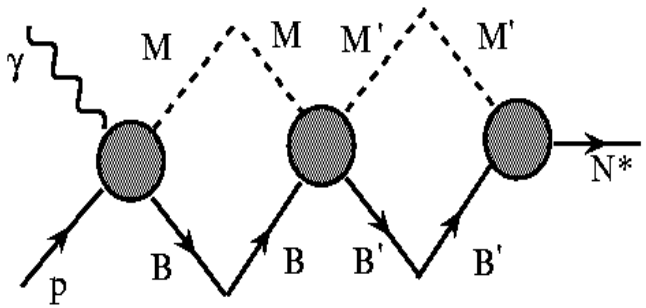


error bars include systematic uncertainties

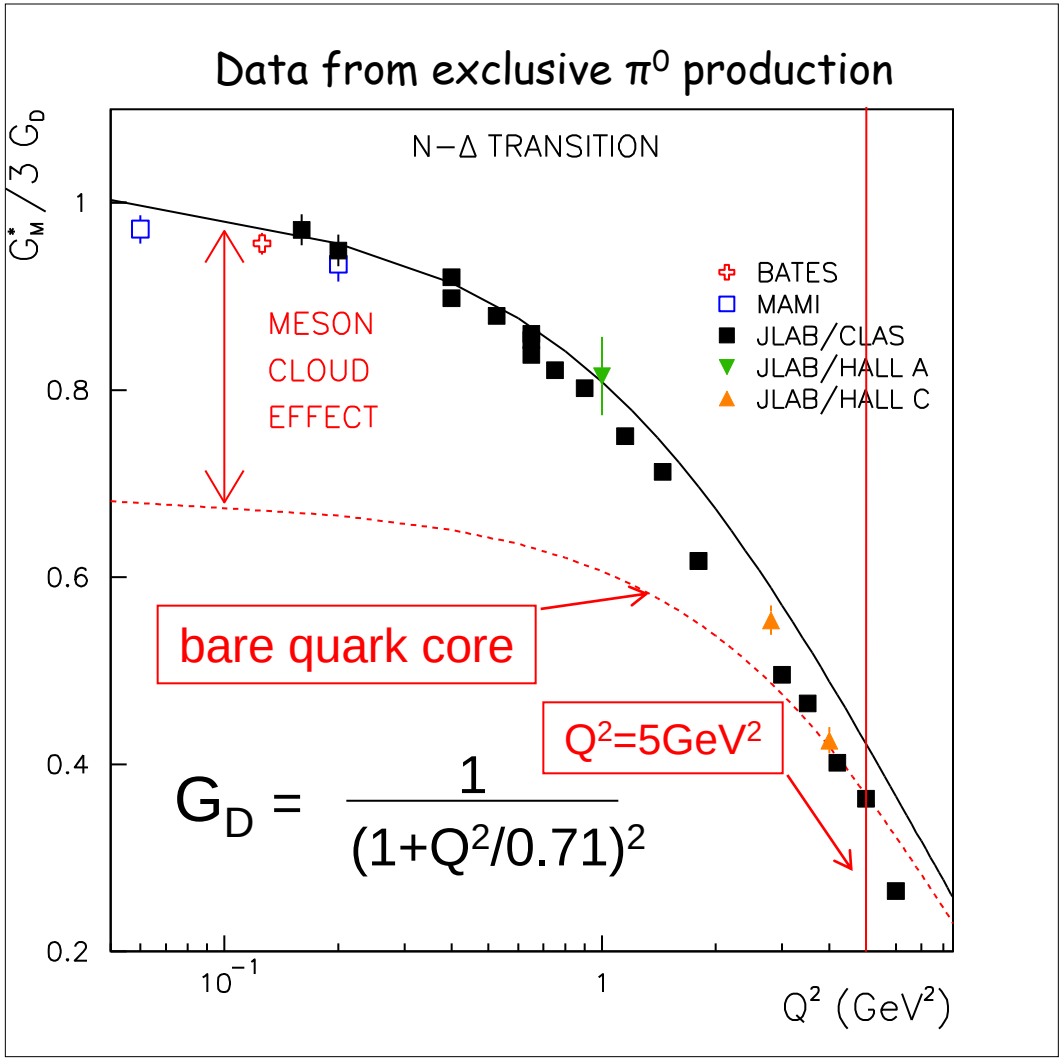
M.Giannini/ E.Santopinto hyper-centric CQM

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

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

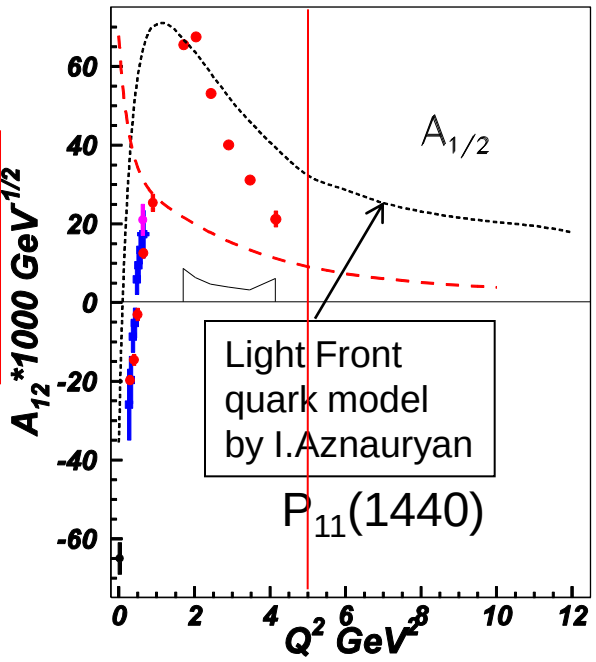


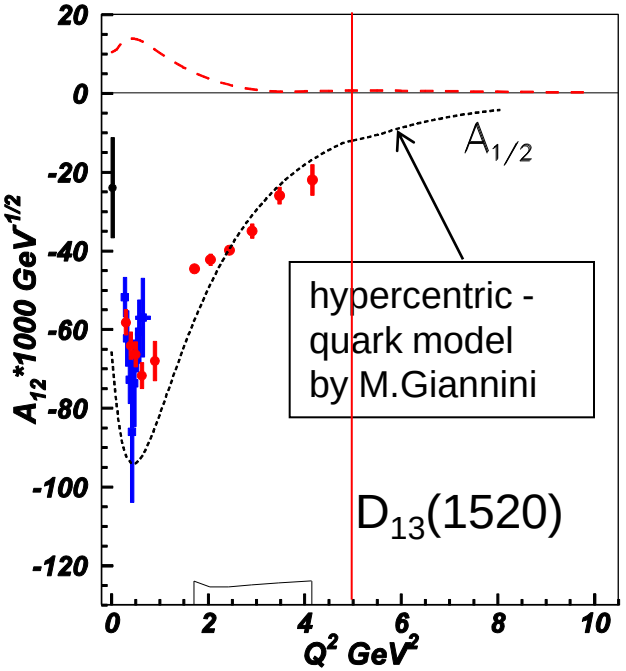
Within the framework of relativistic QM [B.Julia-Diaz *et al.*, PRC 69, 035212 (2004)], the bare-core contribution is very well described by the three-quark component of the wf.



Meson-baryon dressing / Quark core contributions in the $A_{1/2}$ electrocouplings of the $P_{11}(1440)$ & $D_{13}(1520)$ states.

Estimates from EBAC for the MB dressing: B.Julia-Diaz *et al*., PRC 76, 5201 (2007).





- MB dressing effects have substantial contribution to low lying N* electrouplings at Q^2<1.0 GeV^2 and gradually decrease with Q^2;
- Contribution from dressed quarks increases with Q^2 and are expected to be dominant at Q^2>5.0 GeV^2.

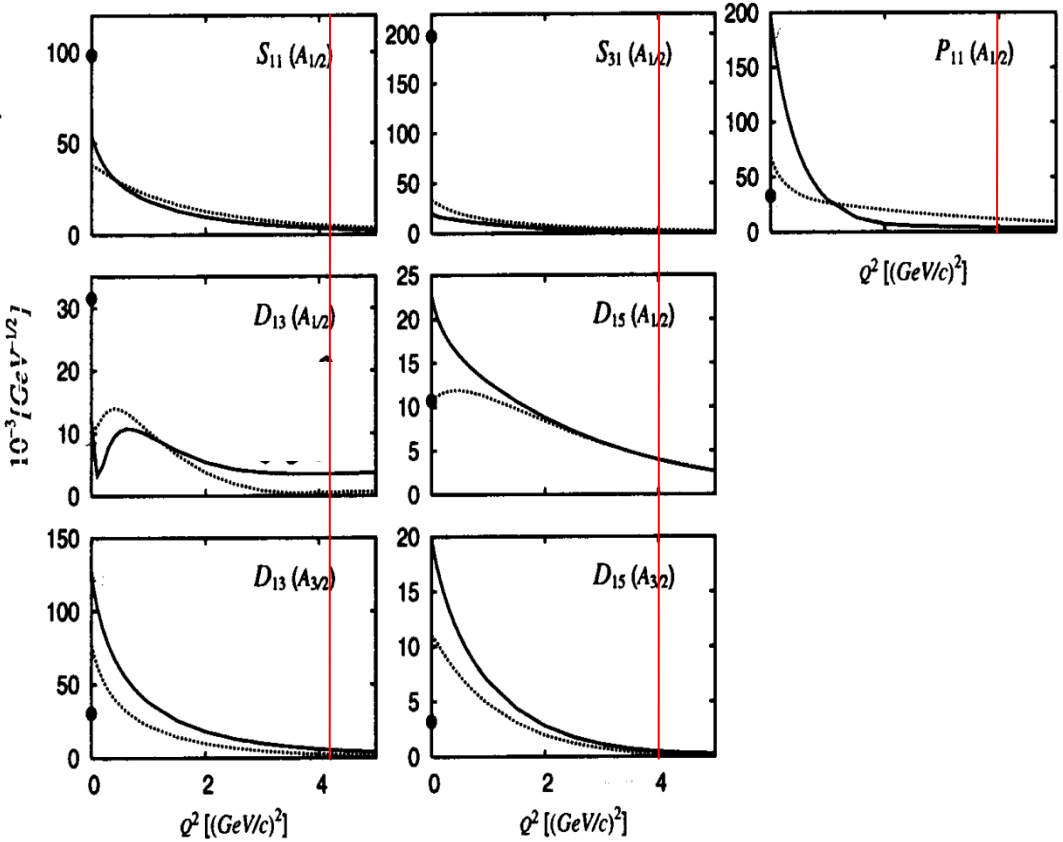
New regime in N* excitation at high Q^2

- **the photons of high virtuality penetrate meson-baryon cloud and interact mostly to quark core**

- **data on N* electrocouplings at high Q^2 allow us to access quark degrees of freedom, getting rid of meson-baryon cloud.**

- **can be obtained at $5<Q^2<10$ GeV^2 after 12 GeV Upgrade with CLAS12 for majority of N* with masses less then 3.0 GeV**

EBAC calculations for meson-baryon cloud of low lying N*'s.



B.Julia-Diaz, T-S.H.Lee, et.al, Phys. Rev. C77, 045205 (2008).

Electrocouplings of [70,1-] $SU_{sf}(6)$-plet states from Nπ/Nππ CLAS data in comparison with quark model expectations

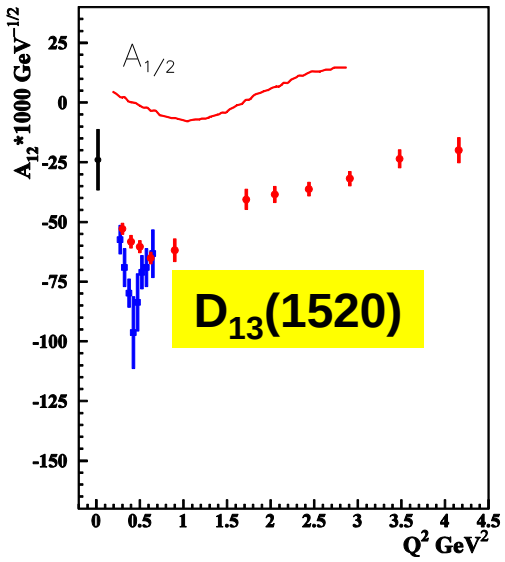
Nππ preliminary

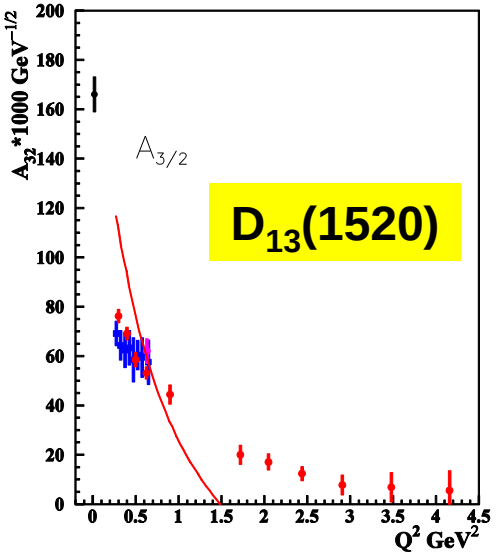
Nπ

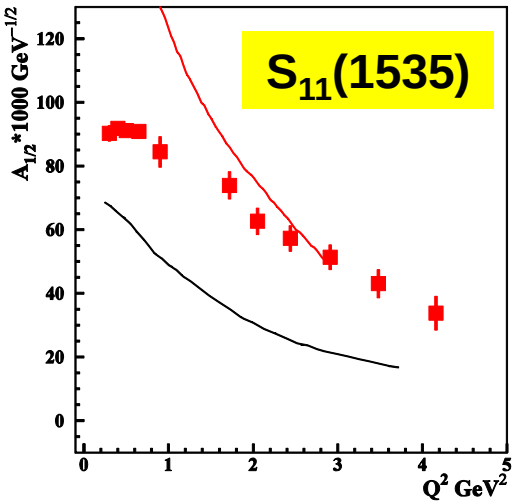
Light front models:

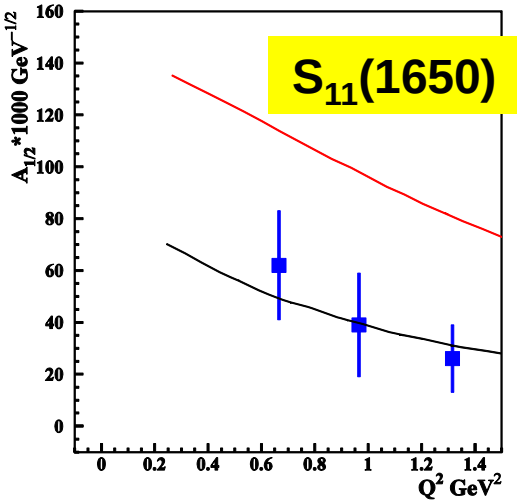
S.Capstick: each N* state is described by single h.o. 3q configuration

S.Simula: Mass operator is diagonalized, utilizing a large h.o. basis for 3q configurations







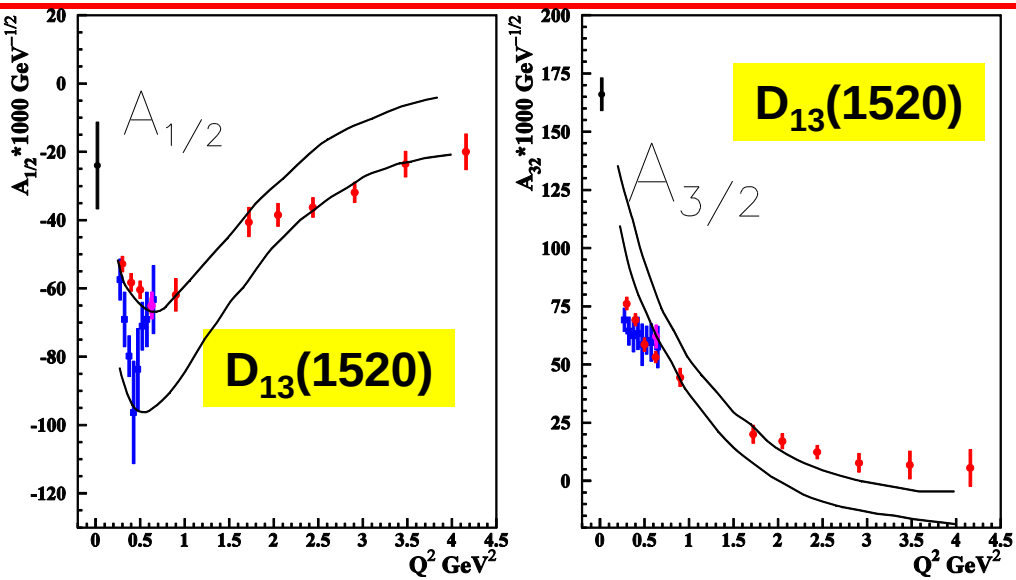


Electrocouplings of [70,1-] $SU_{sf}(6)$-plet states from $N\pi/N\pi\pi$ CLAS data and their description in SQTM approach

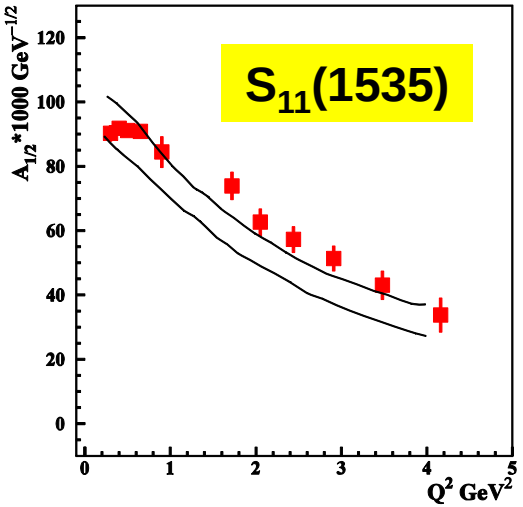
- **SU(6) spin-flavor symmetry for quark binding interactions**

- **Dominant contribution from single quark transition operator:**

$$A L_+ + B L_0 \sigma_+ + C \sigma_0 L_+ + D \sigma_- L_+ L_+$$



World data before CLAS measurements on transverse electrocouplings of $D_{13}(1520)$ and $S_{11}(1535)$ states (the areas between solid lines) allowed us to predict transverse electrocouplings for others [70,1-] states (the areas between solid lines on the next slide), utilizing SU(6) symmetry relations.



V.D. Burkert et al., Phys. Rev. C76, 035204 (2003).

Electrocouplings of [70,1-] $SU_{sf}(6)$-plet states from $N\pi/N\pi\pi$ CLAS data and their description in SQTM approach

SQTM predictions are consistent with major features in the CLAS data, offering an indication for:

- **relevance of quark degrees of freedom;**

- **substantial contribution to quark binding from interactions that poses SU(6) spin-flavor symmetry;**

- **considerable contribution from single quark transition operator to N-N* transition e.m. current.**