The models for evaluation of $\gamma_v NN^*$ electrocouplings from the $N\pi$, $N\pi\pi$ electroproduction data and their extension for photon virtualities up to 12 GeV^2.

presented by V.I.Mokeev

Major objective of the Meeting

Determine the prospects for extension of the model descriptions of non-resonant $N\pi$,$N\pi\pi$ electroproduction amplitudes at $1.1<W<2.0$ GeV into the area of photon virtualities Q^2 from 3.0 to 12 GeV^2 in order to provide the tools for reliable evaluation of N* electrocouplings from the data of these channels, that will be obtained with the CLAS12 detector after 12 GeV Upgrade.

Model capabilities to provide maximal coverage of the final hadron phase space, and ,in particular, to reproduce angular distributions in a full range of the final hadron emission angles are essential for reliable extraction on N* parameters

Nucleon Resonance Studies with CLAS12

D. Arndt[4], H. Avakian[6], I. Aznauryan[11], A. Biselli[3], W.J. Briscoe[4], **V. Burkert[6]**, V.V. Chesnokov[7], **P.L. Cole[5]**, D.S. Dale[5], C. Djalali[10], L. Elouadrhiri[6], G.V. Fedotov[7], T.A. Forest[5], E.N. Golovach[7], **R.W. Gothe*[10]**, Y. Ilieva[10], B.S. Ishkhanov[7], E.L. Isupov[7], **K. Joo[9]**, T.-S.H. Lee[1,2], **V. Mokeev*[6]**, M. Paris[4], K. Park[10], N.V. Shvedunov[7], G. Stancari[5], M. Stancari[5], S. Stepanyan[6], **P. Stoler[8]**, I. Strakovsky[4], S. Strauch[10], D. Tedeschi[10], M. Ungaro[9], R. Workman[4], and the CLAS Collaboration

JLab PAC 34, January 26-30, 2009
Approved for 60 days beamtime

http://www.physics.sc.edu/~gothe/research/pub/nstar12-12-08.pdf.

Argonne National Laboratory (IL,USA)[1], Excited Baryon Analysis Center (VA,USA)[2], Fairfield University (CT, USA)[3], George Washington University (DC, USA)[4], Idaho State University (ID, USA)[5], Jefferson Lab (VA, USA)[6], Moscow State University (Russia)[7], Rensselaer Polytechnic Institute (NY, USA)[8], University of Connecticut (CT, USA)[9], University of South Carolina (SC, USA)[10], and Yerevan Physics Institute (Armenia) [11]

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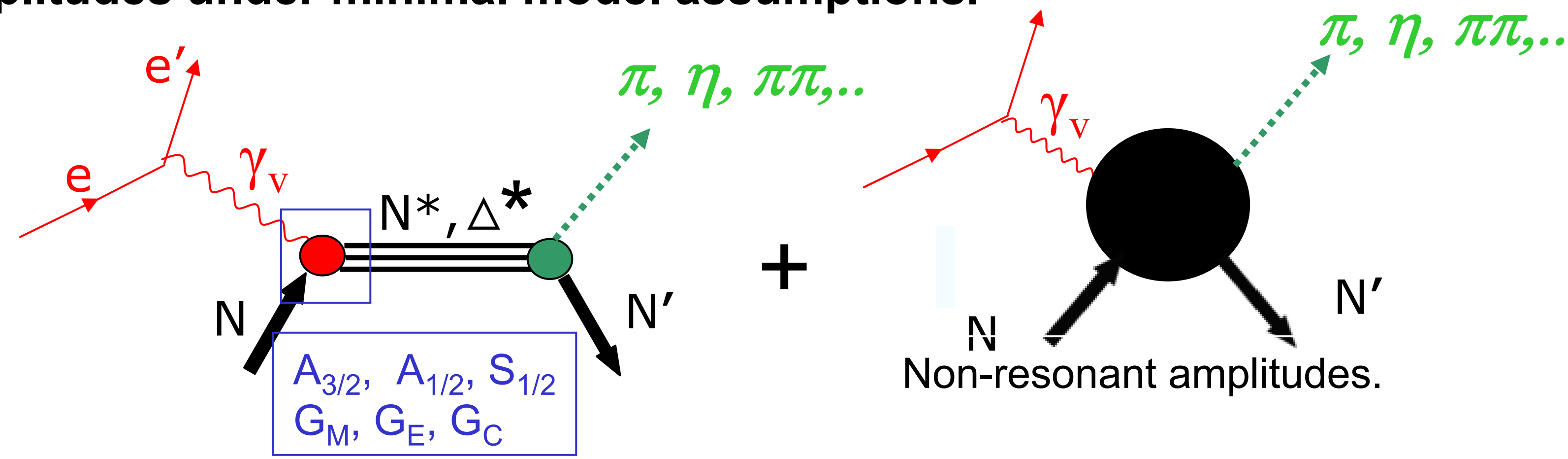
Development of approaches that will be capable to relate phenomenological information on N* electrcocouplings at high photon virtualities to non perturbative strong interaction mechanisms, that are responsible for formation of ground and excited nucleon states from quark and gluons, and to study their emergence from QCD

The current plans are outlined in the paper:
"Theory Support for the Excited Baryon Program at the JLAB 12 GeV Upgrade", arXiv:0907.1901 [nucl-th],[nucl-ex],[lat-ph], JLAB-PHY-09-993.

How N* electrocouplings can be accessed

- **Isolate the resonant part of production amplitudes by fitting the measured observables within the framework of reaction models, which are rigorously tested against data.**
- **N* electrocouplings can then be determined from resonant amplitudes under minimal model assumptions.**



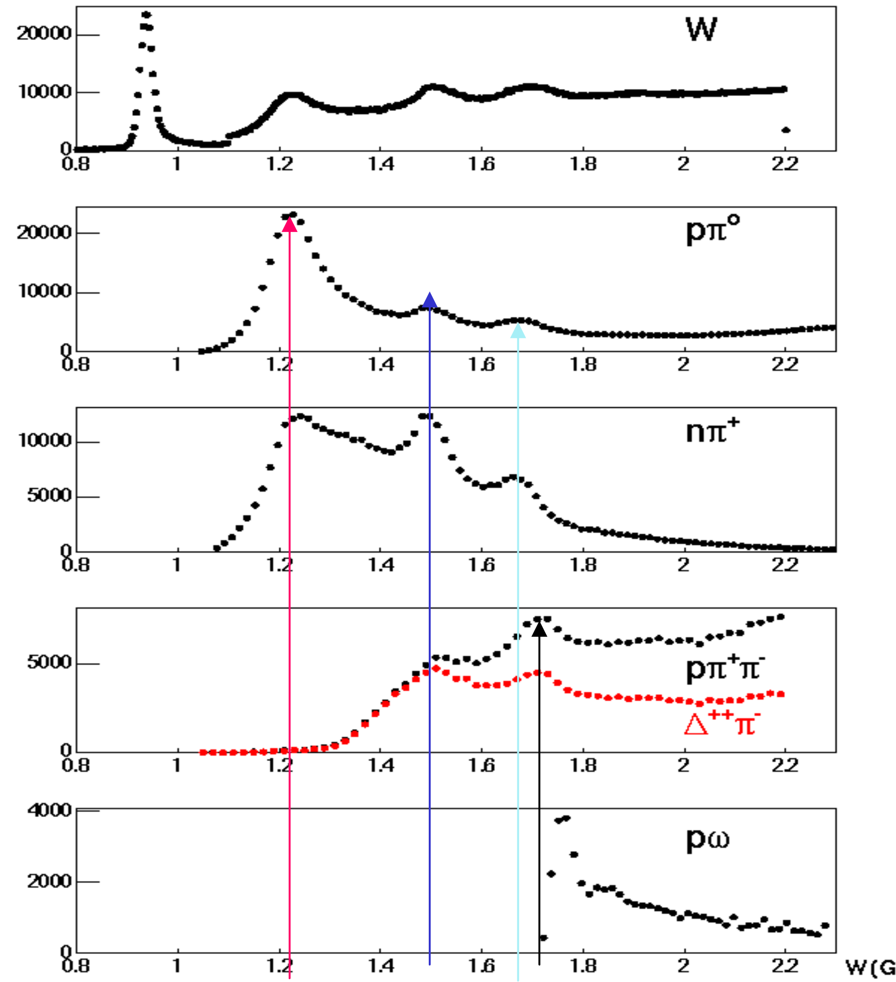
Consistent results on N* electrocouplings obtained in analyses of various meson channels (e.g. *πN, ηp, ππN) with entirely different non-resonant* amplitudes will show that they are determined reliably

Advanced coupled-channel analysis methods are being developing at EBAC: B.Julia-Diaz, T-S.H.Lee *et al.*, PRC76, 065201 (2007);B.Julia-Diaz, et al., arXiv:0904.1918[nucl-th]

Why $N\pi/N\pi\pi$ electroproduction channels are important

- $N\pi/N\pi\pi$ channels are the two major contributors in N* excitation region;
- these two channels combined are sensitive to almost all excited proton states;
- they are strongly coupled by $\pi N \rightarrow \pi\pi N$ final state interaction;
- may substantially affect exclusive channels having smaller cross sections, such as ηp, $K\Lambda$, and $K\Sigma$.

CLAS data on meson electroproduction at $Q^2 < 4.0$ GeV^2

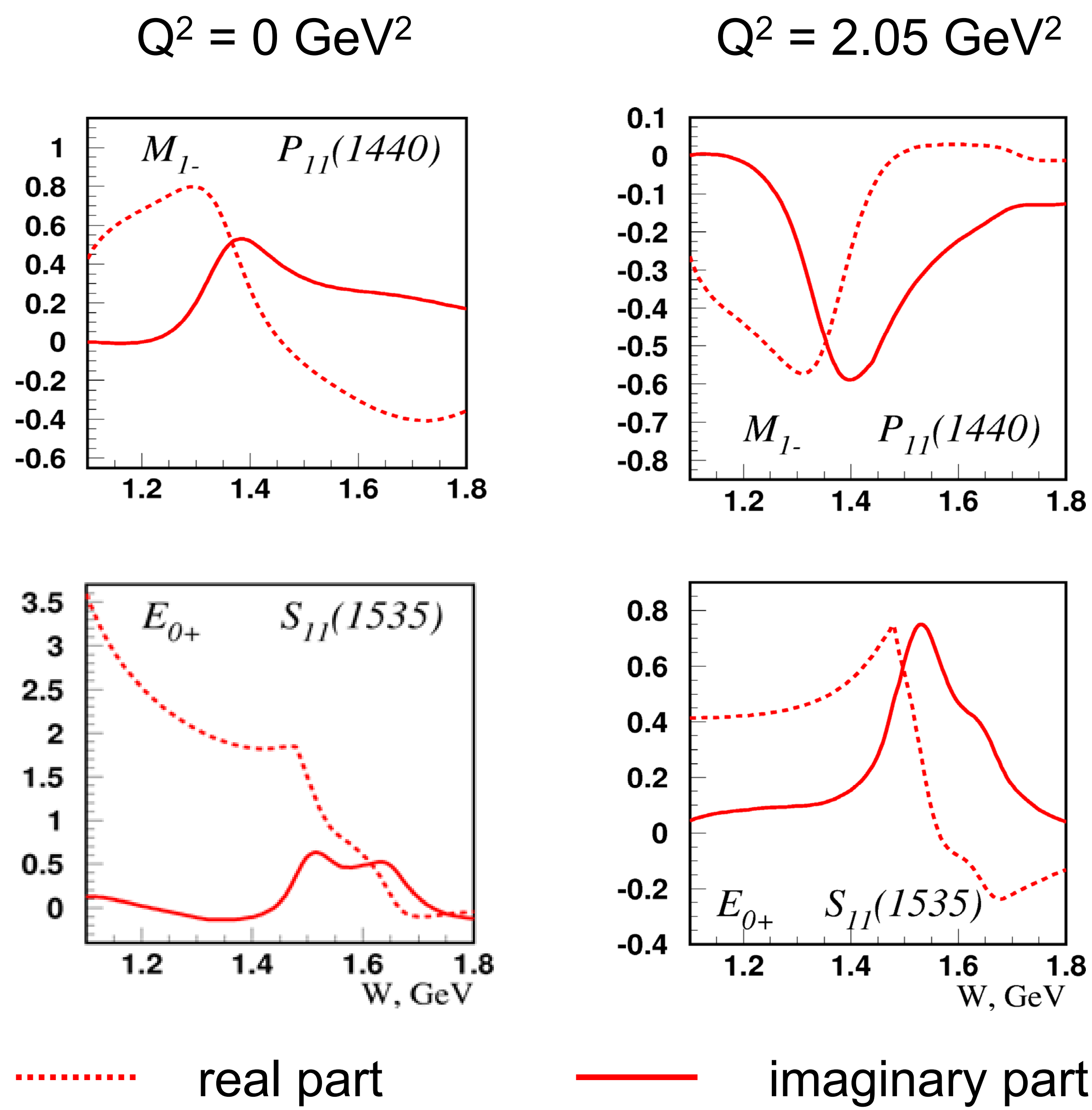


Therefore knowledge on $N\pi/N\pi\pi$ electro production mechanisms is key for the entire N* studies at high photon virtualities with CLAS12 detector

Energy-Dependence of π^+ Multipoles for P_{11}, S_{11}

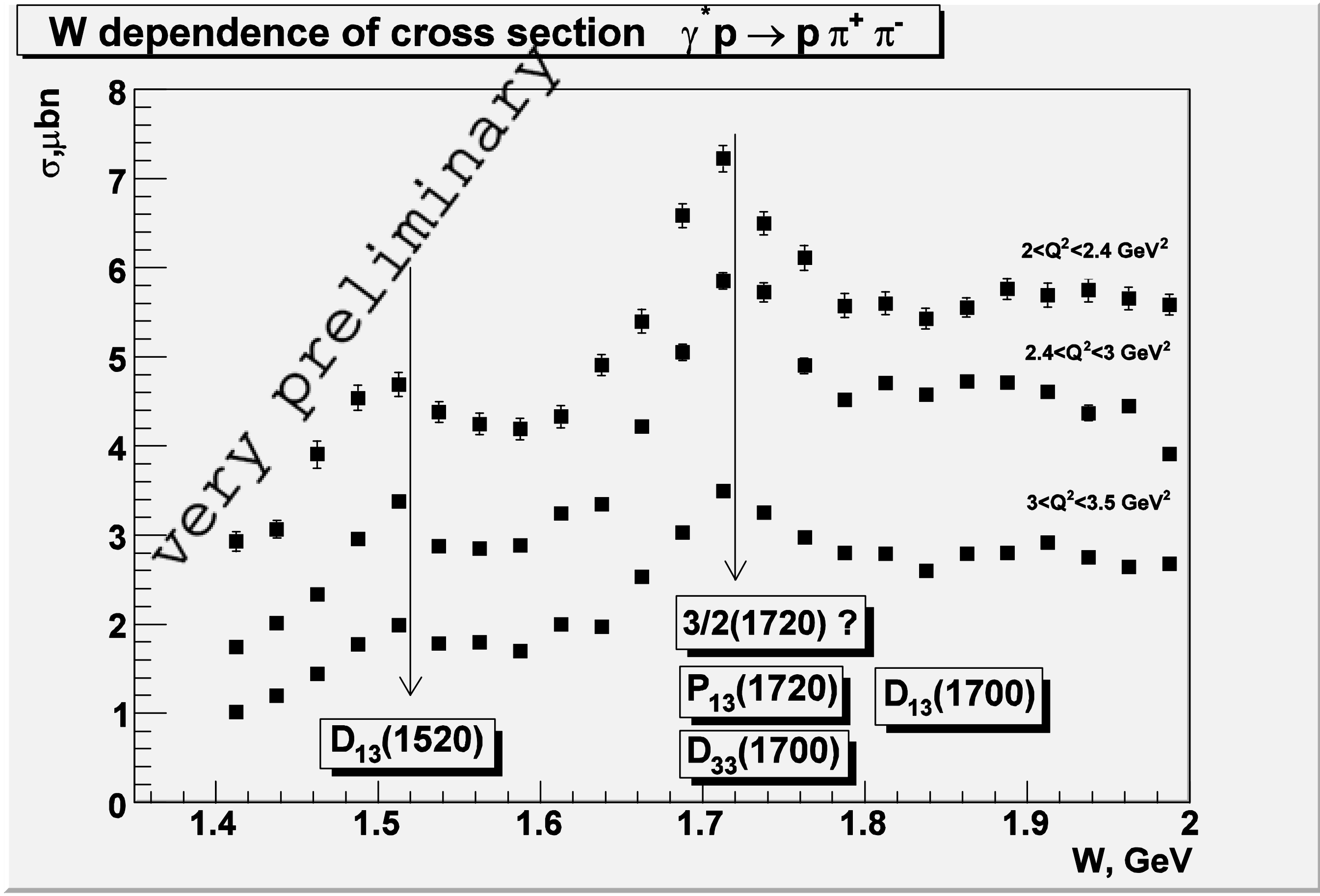
I. Aznauryan (UIM)

Resonance contributions become more pronounced at higher Q^2.



Resonance signals in the CLAS data on $N\pi\pi$ electroproduction at $2.0 < Q^2 < 5.0$ GeV2

Resonance structures are clearly seen in an entire Q^2 area covered by the CLAS data on $N\pi\pi$ electroproduction

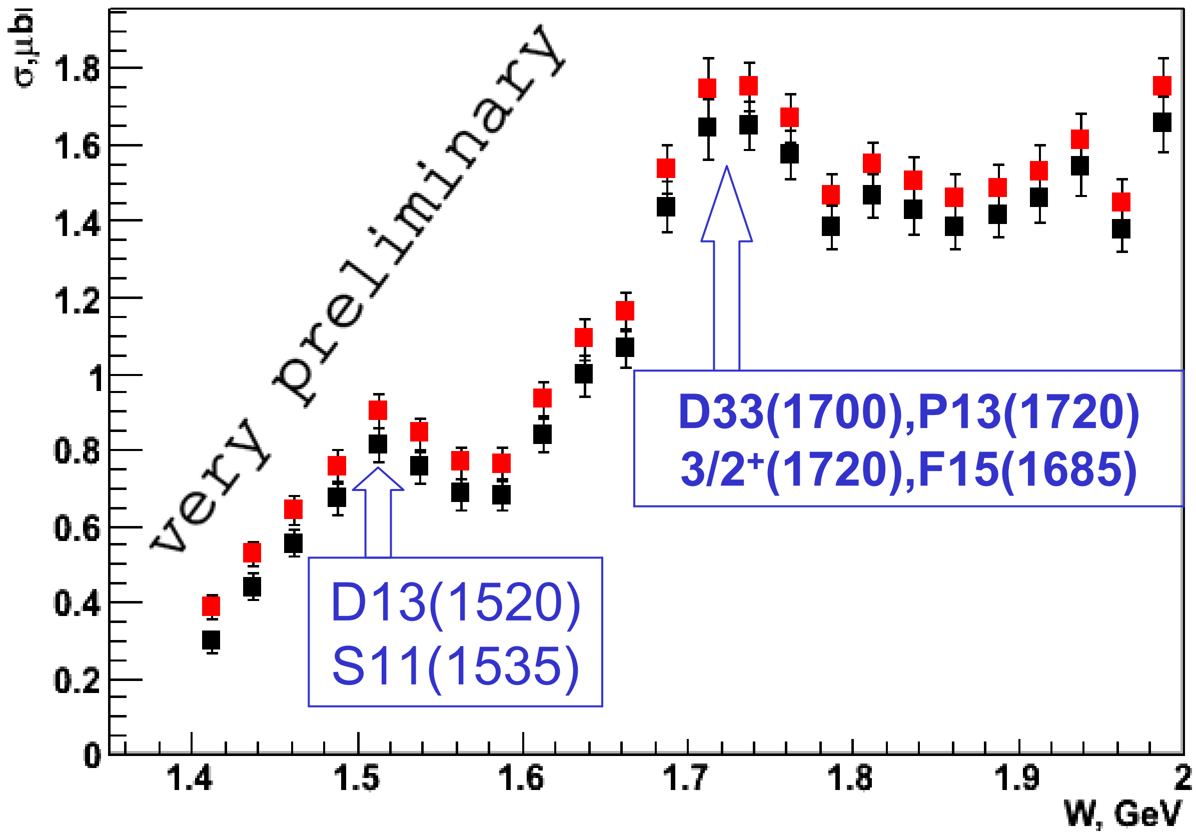


Resonances with masses above 1.65 GeV becomes more pronounced at high Q^2.

Resonance signals in Nππ electroproduction at high Q^2.

Resonant contributions in Nπ and Nππ exclusive channels remains substantial at high Q^2. It makes possible to determine resonance electropcouplings at $3.0<Q^2<12.$ GeV^2

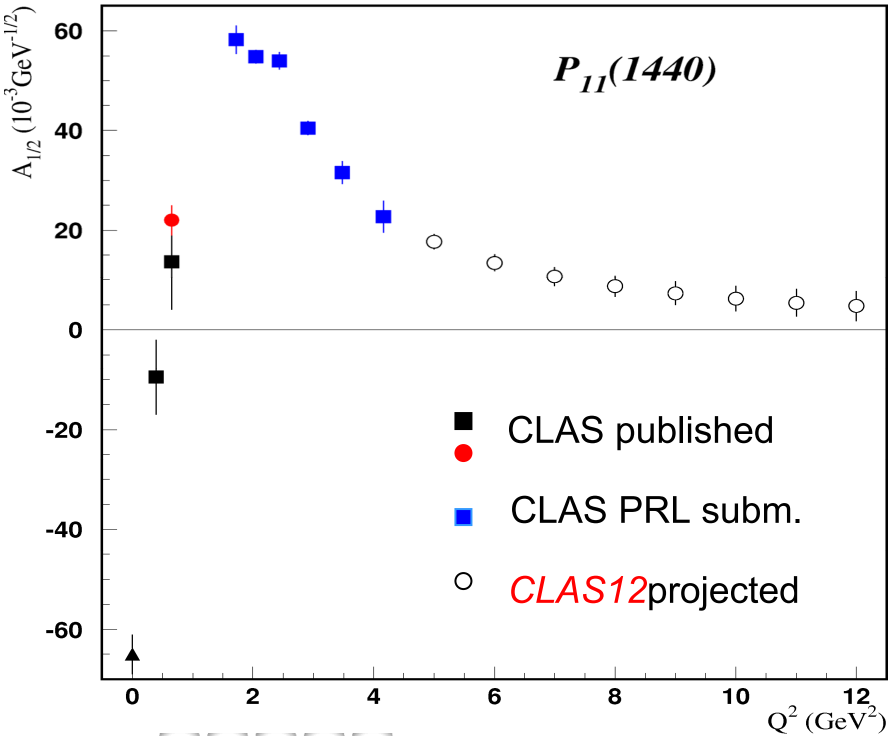
Fully integrated 2π cross section at Q^2 from 4.5 to 5.2 GeV^2

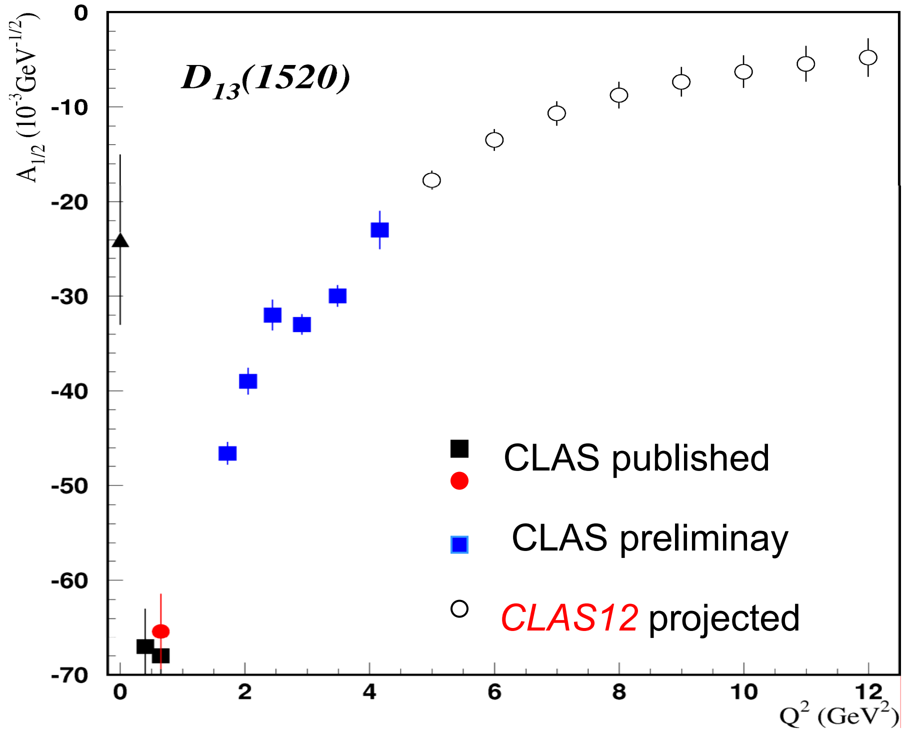


CLAS12 Projections for N* Transitions

The projected electrocouplings were estimated based on expected counting rate and requirements for statistical data accuracy needed in order to obtain N* electrocouplings from the data on Nπ and Nππ electroproduction

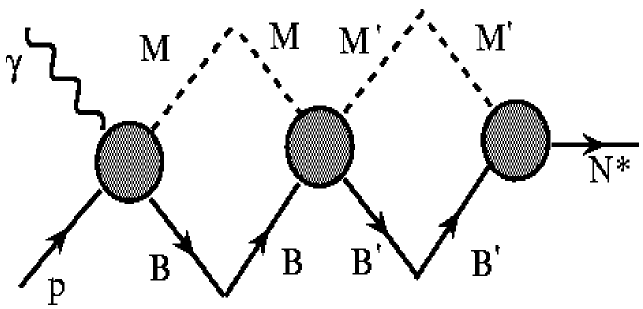
Unexplored area of $5. < Q^2 < 12$ GeV^2 will be covered for the first time. These distance scales correspond to a new regime in N* excitation



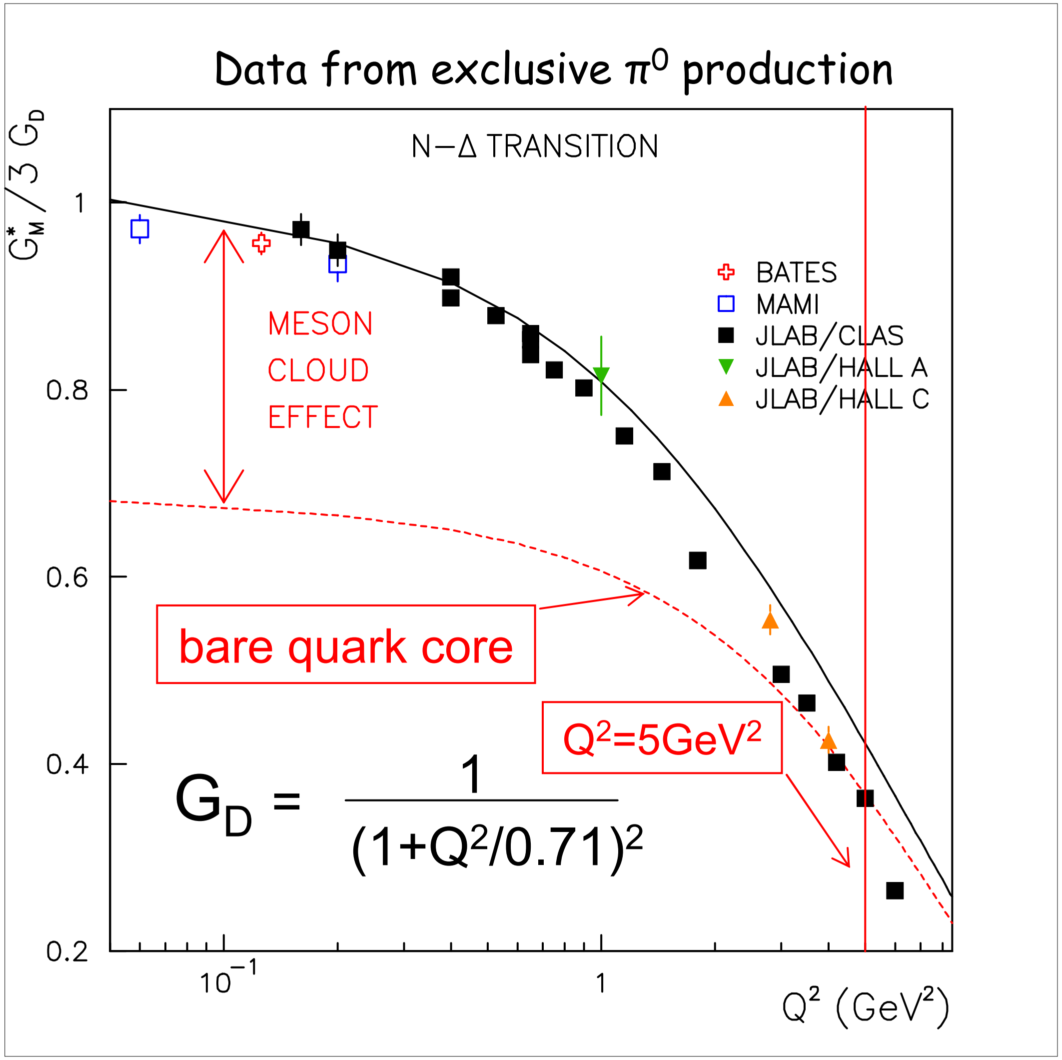


Meson-baryon vs Quark contributions in NΔ Transition Form Factor – $G_{M.}$ EBAC analysis.

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

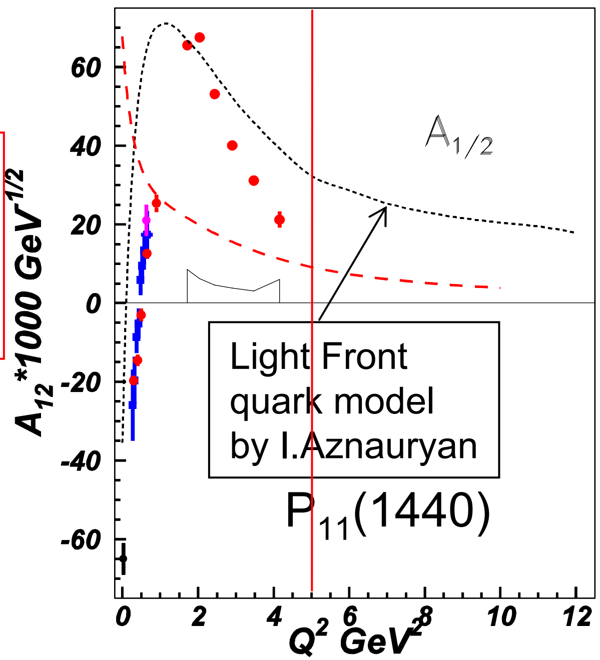


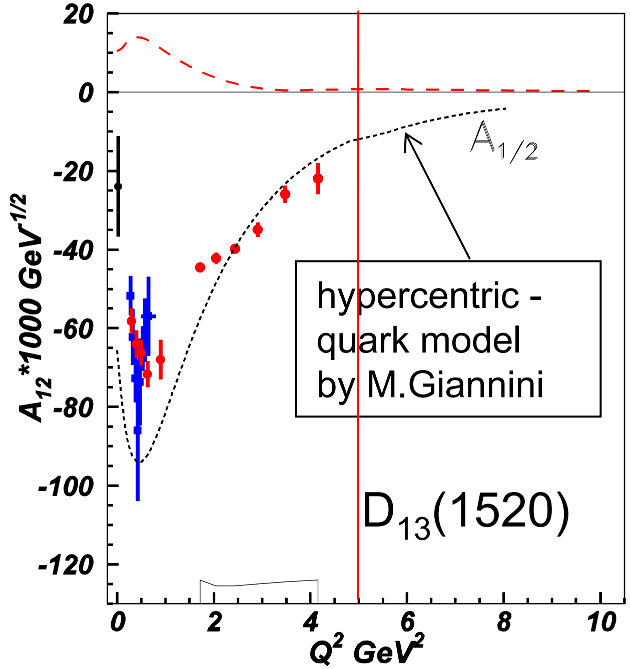
Within the framework of relativistic QM [B.Julia-Diaz *et al.*, PRC 69, 035212 (2004)], the bare-core contribution is very well described by the three-quark component of the wf.



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 (absolute values): B.Julia-Diaz *et al*., PRC 76, 5201 (2007).





- Contribution from dressed quarks increases with Q^2 and are expected to be dominant at Q^2>5.0 GeV^2.
- **Quark degrees of freedom are expected to play an important role also in non resonant amplitudes at these distance scales. Therefore, for extraction of N* electrocouplings we need the models accounting for relevant quark degrees of freedom in non-resonant reaction amplitudes**

Nπ CLAS data at low & high Q^2

Number of data points > 83,000, W < 1.7 GeV

Observable	Q^2 [GeV²]	Number of Data points
$d\sigma/d\Omega(\pi^0)$	0.35-1.6	31 018
$d\sigma/d\Omega(\pi^+)$	0.25-0.65 1.7-4.3	13 264 33 000
$A_e(\pi^0)$	0.40 0.65	956 805
$A_e(\pi^+)$	0.40 0.65 1.7 - 4.3	918 812 3 300
$d\sigma/d\Omega(\eta)$	0.375 0.750	172 412

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).

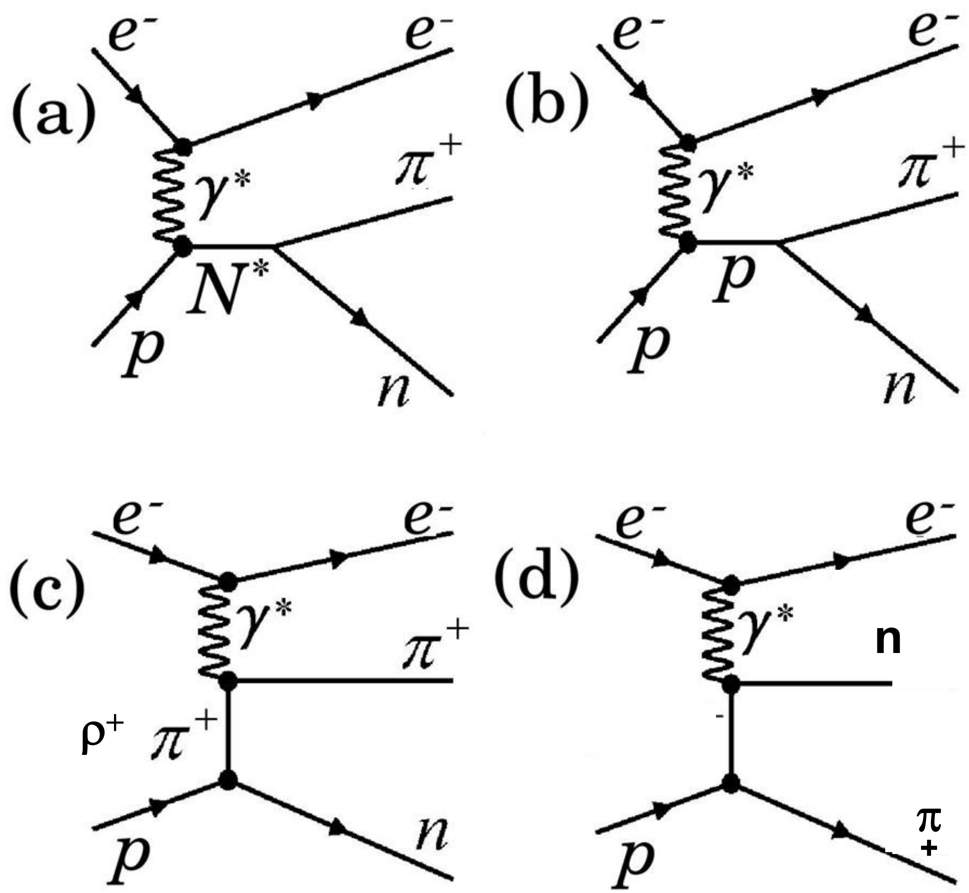
Prelim. high Q^2 results on $D_{13}(1520)$, $S_{11}(1535)$:
V.Burkert, AIP Conf.Proc. 1056, 248 (2008).

full data set in:
http://clasweb.jlab.org/physicsdb/

Unitary Isobar Model (UIM) for Nπ electroproduction

Non-resonant contributions were described by gauge invariant Born terms:

- pole/reggeized meson *t*-channel exchange;
- *s*- and *u*-nucleon terms.



Final-state πN rescattering was taken into account through the K-matrix approximation

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

Fixed-*t* Dispersion Relations for invariant Ball amplitudes (Devenish &Lyth)

$\gamma^* p \rightarrow N\pi$

Dispersion relations for 6 invariant Ball amplitudes:

17 UnsubtractedDispersion Relations

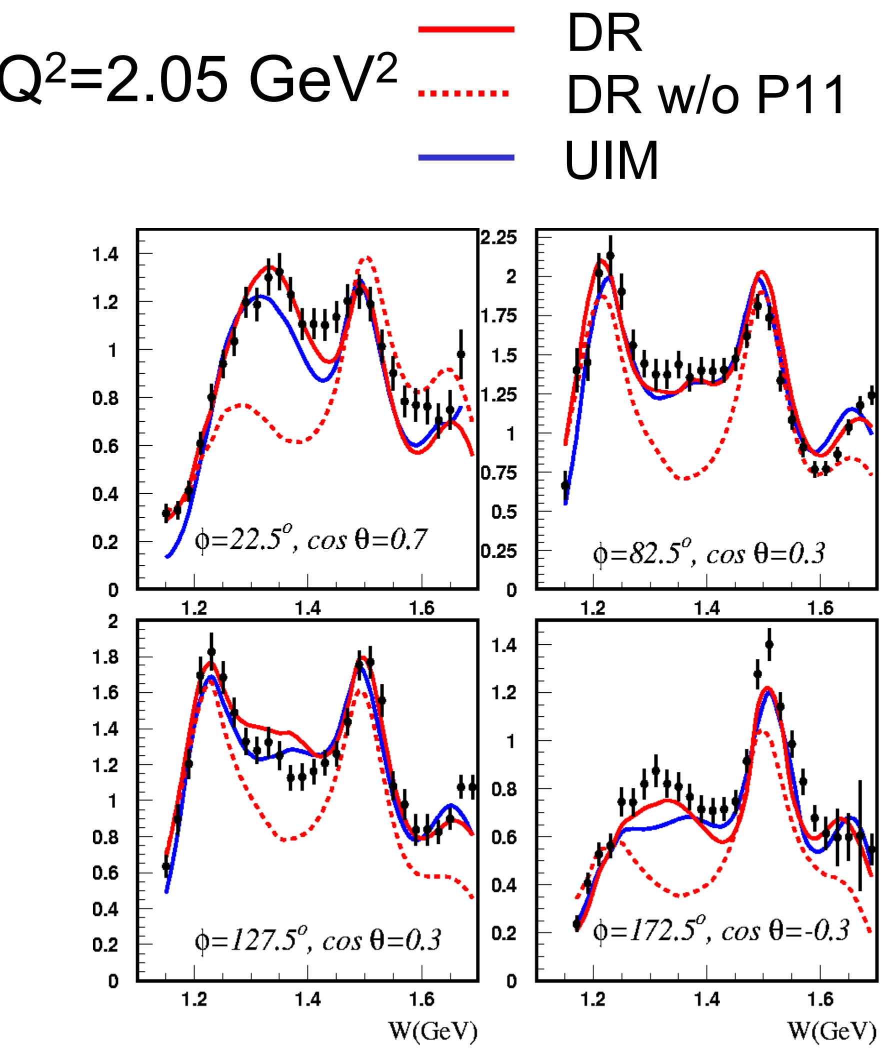
$$ReB_i^{(\pm,0)}(s,t,Q^2)\left[ReB_3^{(+,0)}(s,t,Q^2)\right] = R_i^{(v,s)}(Q^2)\left(\frac{1}{s-m_N^2}+\frac{\eta_i\eta^{(+,-,0)}}{u-m_N^2}\right) + \frac{P}{\pi}\int_{s_{thr}}^{\infty} ImB_i^{(\pm,0)}(s',t,Q^2)\left(\frac{1}{s'-s}+\frac{\eta_i\eta^{(+,-,0)}}{s'-u}\right)ds'$$

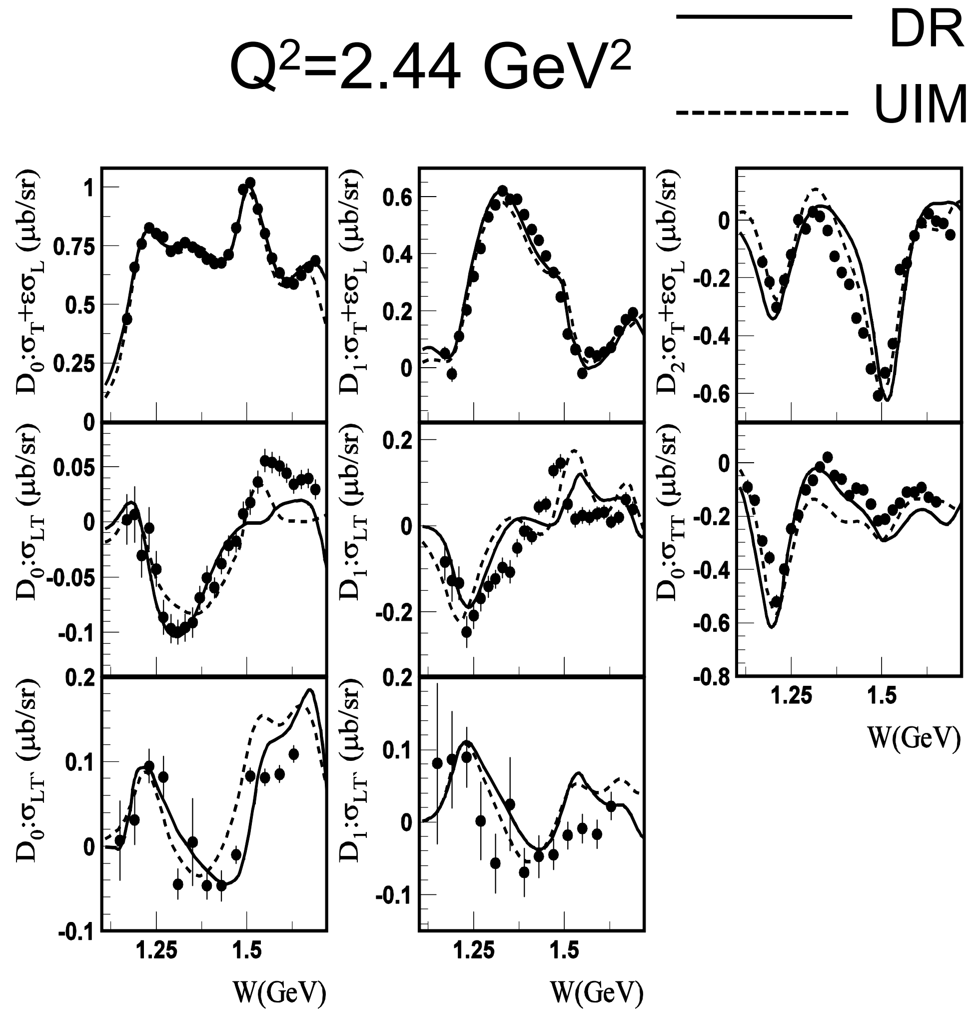
(i=1,2,4,5,6)

1 Subtracted Dispersion Relation

$$ReB_3^{(-)}(s,t,Q^2) = R_3^{(v)}(Q^2)\left(\frac{1}{s-m_N^2}+\frac{1}{u-m_N^2}\right) - eg\frac{F_\pi(Q^2)}{t-m_\pi^2} + f_{sub}(t,Q^2) + \frac{P}{\pi}\int_{s_{thr}}^{\infty} Im\ B_3^{(-)}(s',t,Q^2)\left(\frac{1}{s'-s}+\frac{1}{s'-u}\right)ds'$$

Fits to Nπ diff. cross sections & structure functions





Request for modeling of non-resonant Nπ amplitudes at high Q^2

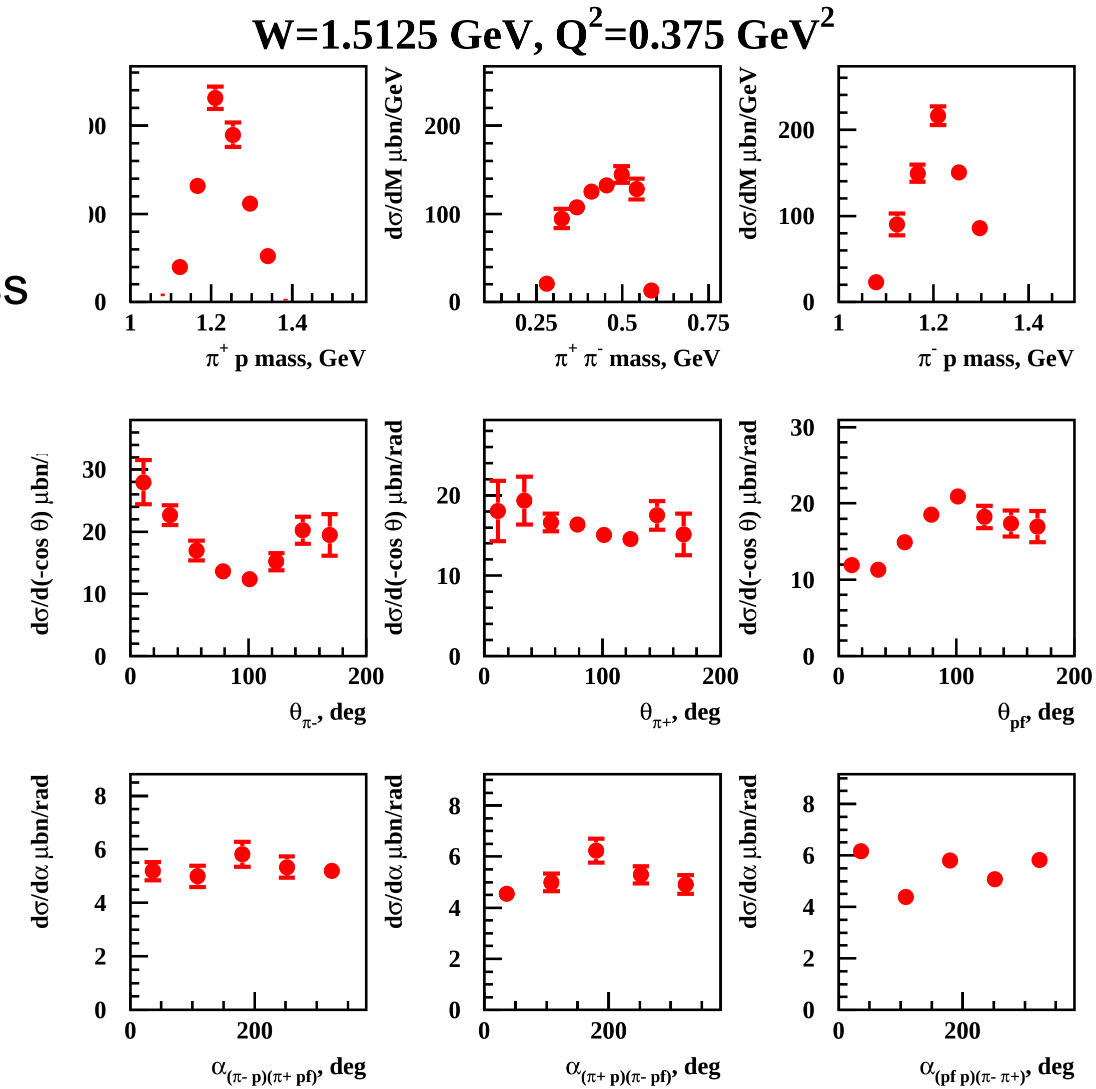
- Evaluate the prospects of describing non-resonant Nπ amplitudes at 1.1<W<2.0 GeV and $3.0<Q^2<12$ GeV^2 employing effective quark degrees of freedom and providing full coverage of the final hadron emission angles.
- Using available Nπ electroproduction data from the CLAS at $3.0<Q^2<5.0$GeV^2, to study the possibilities of complete or partial replacement of currently employing in N* analyses meson-baryon degrees of freedom by quark degrees of freedom.

see full Nπ data sets in:

http://clasweb.jlab.org/physdb/

Nππ electroproduction data from CLAS

The measurements with an unpolarized e⁻ beam onto a proton target offer nine independent differential cross sections in each (W,Q^2) bin.



Number data points > 8200

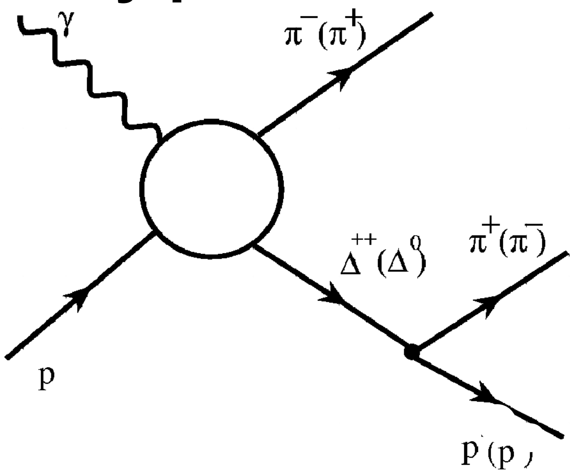
1.3 < W < 2.1 GeV ;

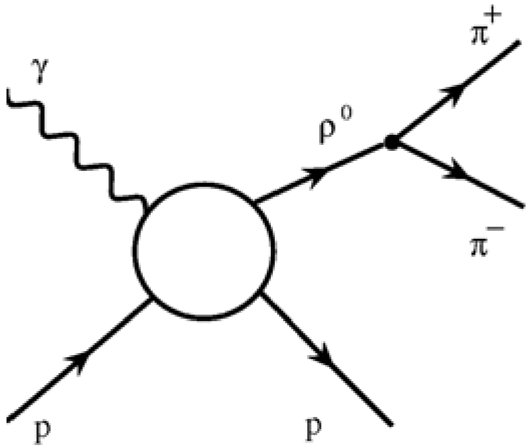
0.25 < Q²< 1.5 GeV²

M. Ripani *et al*., PRL,91, 022002 (2003);
G. Fedotov *et al*., PRC 79, 015204 (2009).

JLAB-MSU meson-baryon model (JM) for $N\pi\pi$ electroproduction.

3-body processes:





Isobar channels included:

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

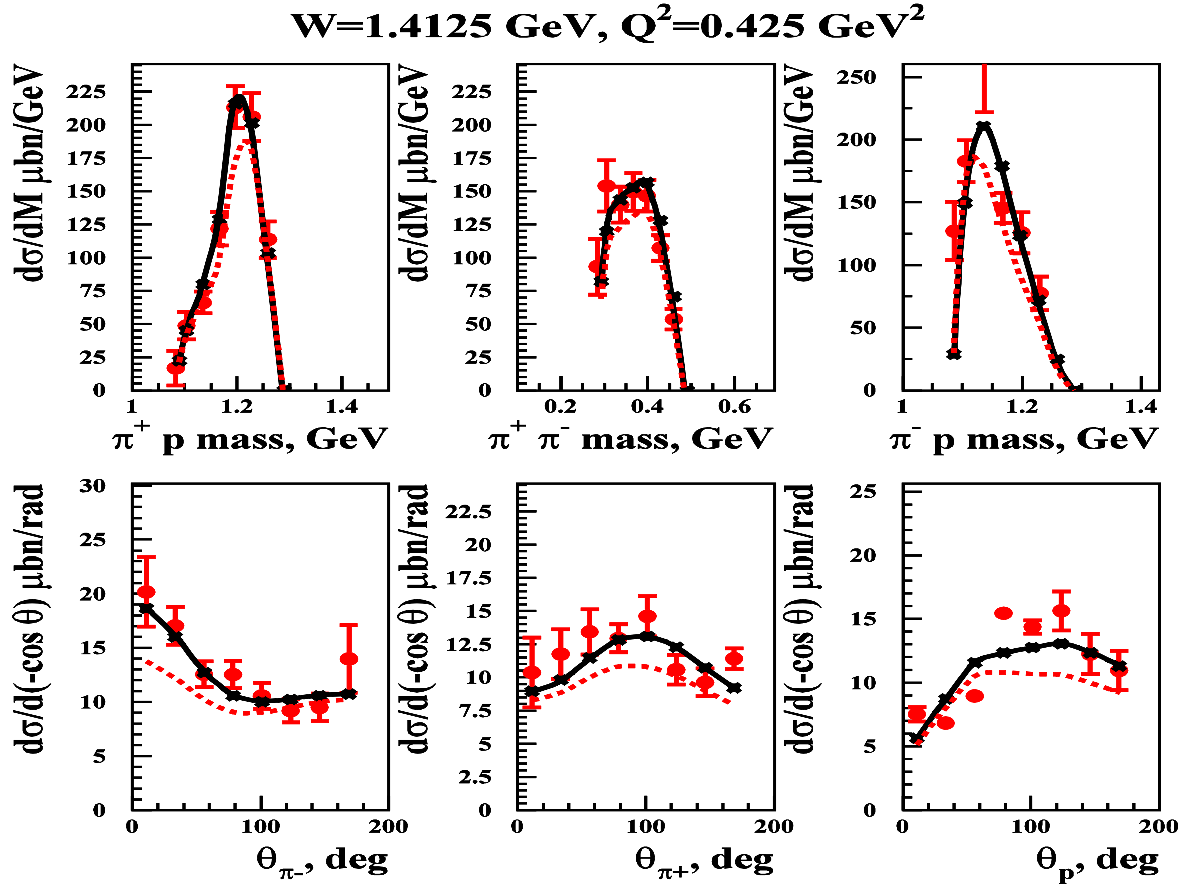
- All well established N*s with $\pi\Delta$ decays and $3/2^+(1720)$ candidate, seen in CLAS 2π data.
- Reggeized Born terms with effective FSI & ISI treatment .
- Extra $\pi\Delta$ contact term.

ρp

•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.

Evidence for extra contact term in $\pi^-\Delta^{++}$ isobar channel.



—— full calculations

------ extra contact term is taken off

Parametrization of extra $\pi\Delta$ contributions

$$M_t = (A(W,Q^2)\varepsilon^{\gamma}_{\mu}\overline{U}_{\Delta_\nu}\gamma^{\mu}U_p P^{\nu}_{\pi} + B(W,Q^2)\varepsilon^{\gamma}_{\nu}\overline{U}_{\Delta_\nu}\gamma^{\mu}U_p(2P^{\mu}_{\pi} - P^{\mu}_{\gamma})) \bullet \frac{1}{t-\Lambda^2}$$

Evidence for extra contact term in $\pi^+\Delta^0$ isobar channel.

full calculation:

extra contact term:

on

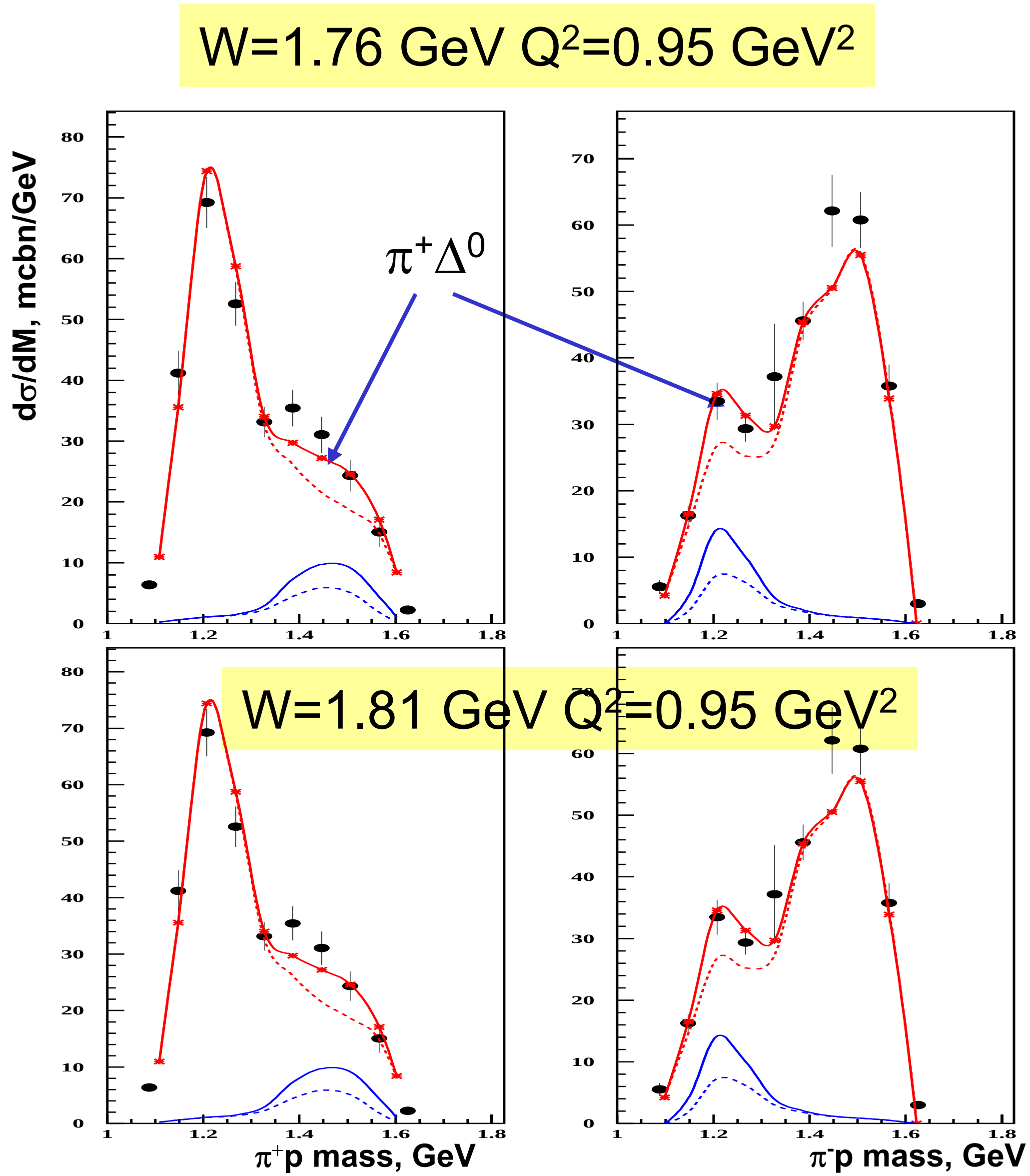
off

$\gamma p \rightarrow \pi^+ \Delta^0$ contributin:

extra contact term:

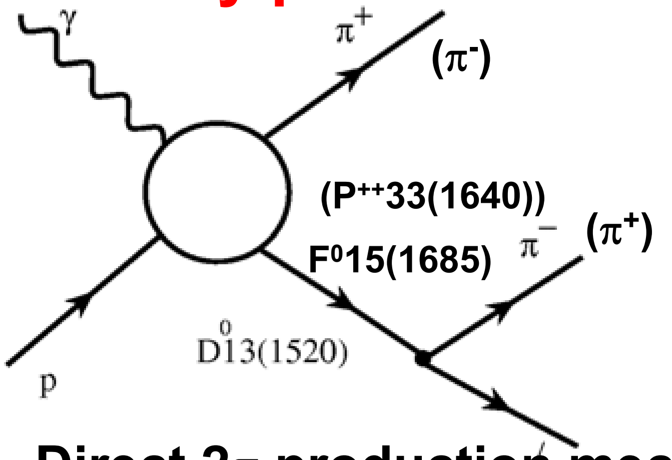
on

off



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

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 mechanisms without formation of unstable hadrons in the intermediate states were established in the CLAS Nππ data analysis for the first time and shown in the slides #25-29. They are most relevant at W<1.65 GeV, contributing <30 % to fully integrated Nππ cross sections.

All details of JM model may be found in:

V. Mokeev, V .Burkert, J. Phys. 69, 012019 (2007);
V. Mokeev *et al.*, arXiv:0809:4158[hep-ph], submitted to PRC

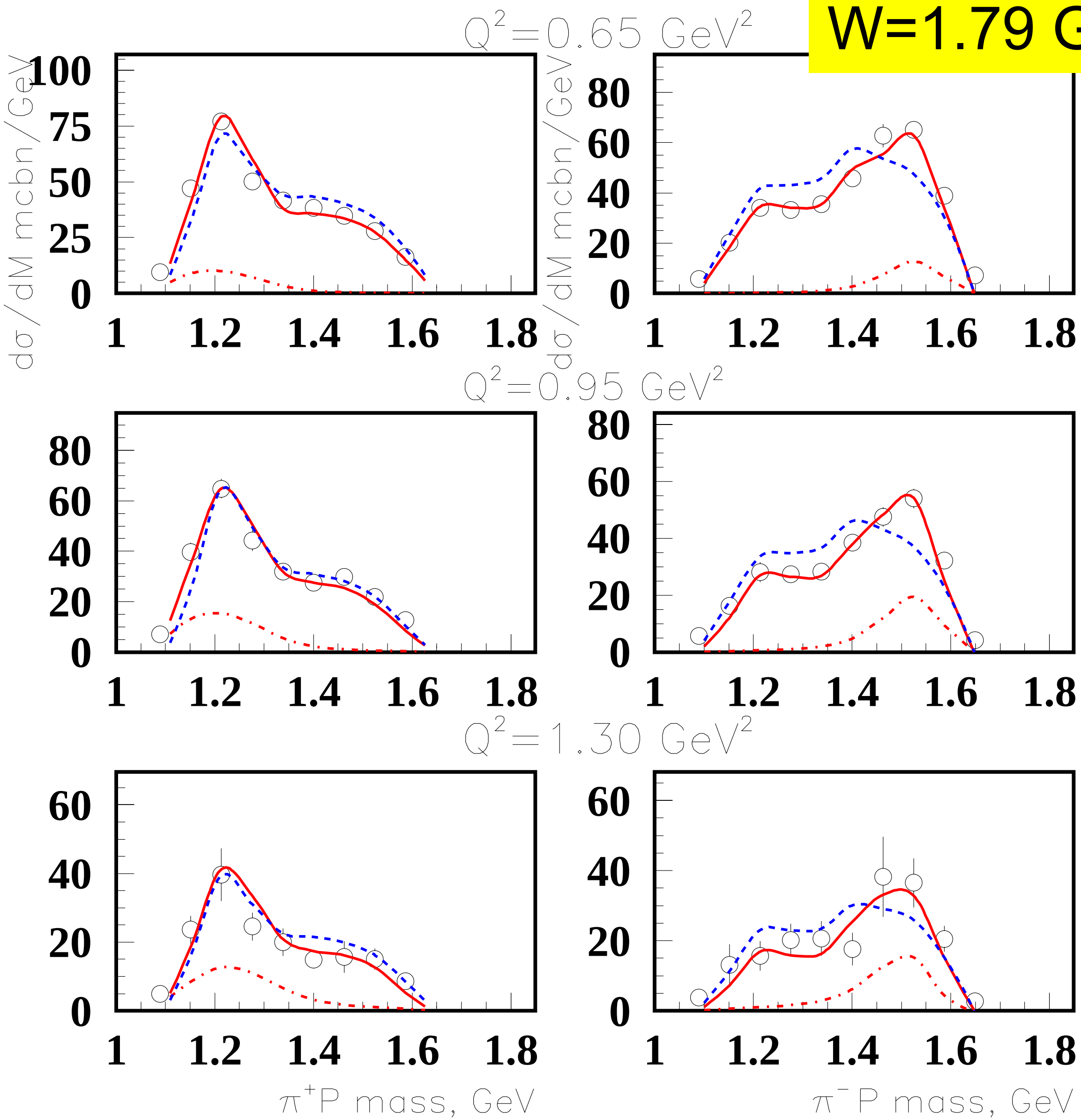
Manifestation of $\pi^+D^0 13(1520)$ isobar channel in the CLAS $N\pi\pi$ data

full calculation:

$\pi^+D^0_{13}(1520)$ channel on

$\pi^+D^0_{13}(1520)$ channel off

$\pi^+D^0 13(1520)$ contribution



Manifestation of $\gamma p \to \pi^- P_{33}^{++}(1640)$ and $\gamma p \to \pi^+ F_{15}(1685)$ isobar channels.

W=1.89 GeV
Q^2=0.95 GeV^2

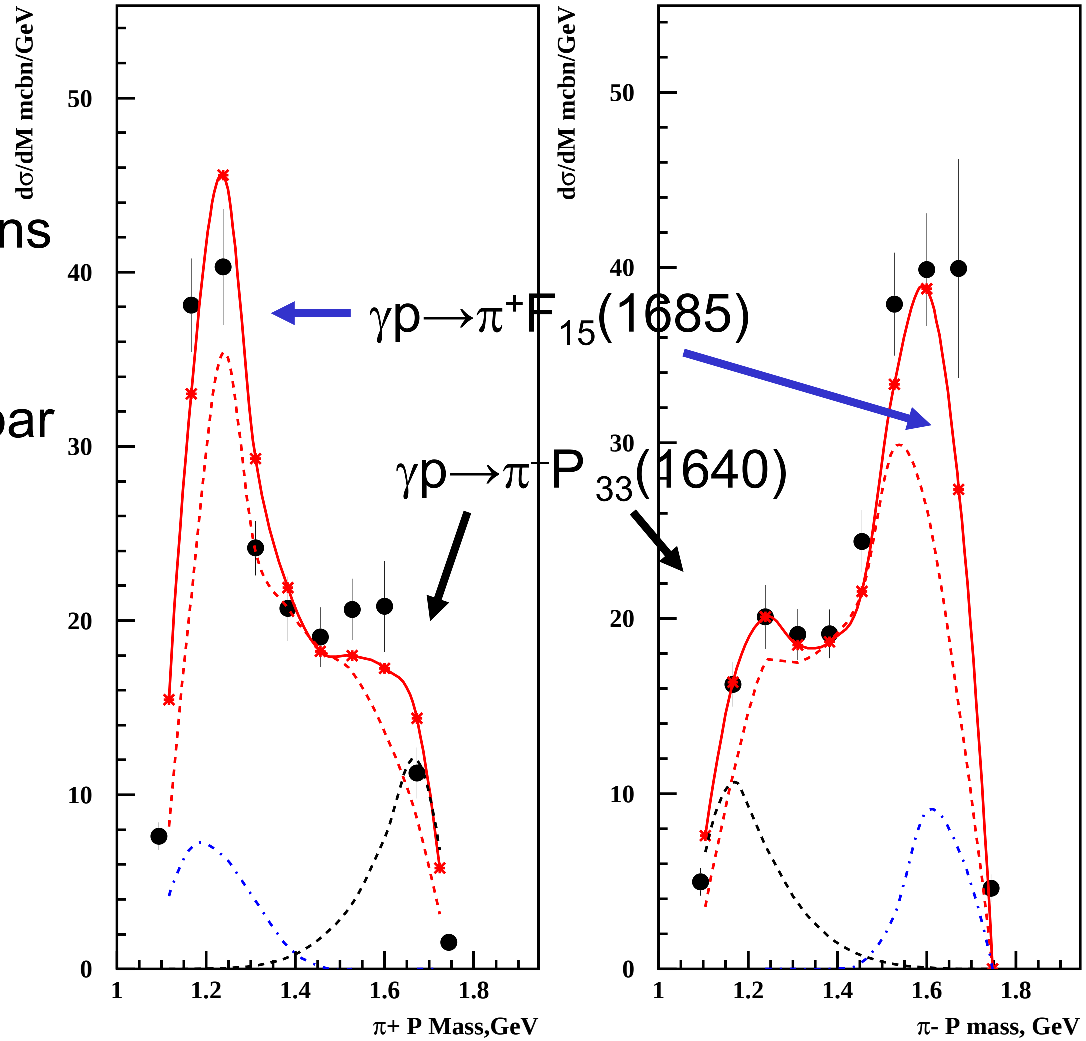
full calculations

$\pi^- P_{33}^{++}(1640)$ and $\pi^+ F_{15}^0(1685)$ isobar channels off

Contributions from isobar channels:

$\pi^- P_{33}^{++}(1640)$

$\pi^+ F_{15}^0(1685)$



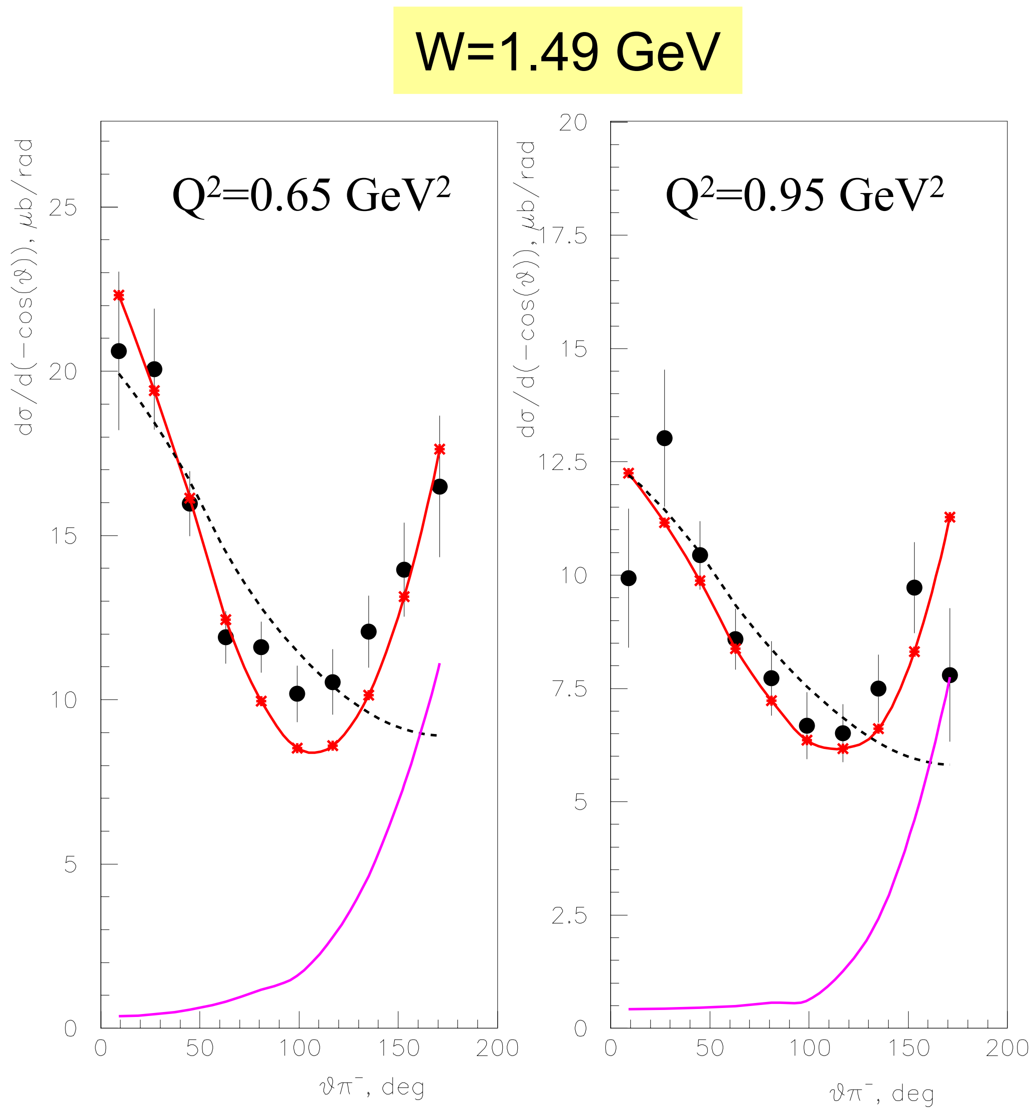
Evidence for exchange processes in direct 2π production from the CLAS Nππ data

Fit of the CLAS data on π^- angular distributions with direct 2π production mechanisms parameterized as :

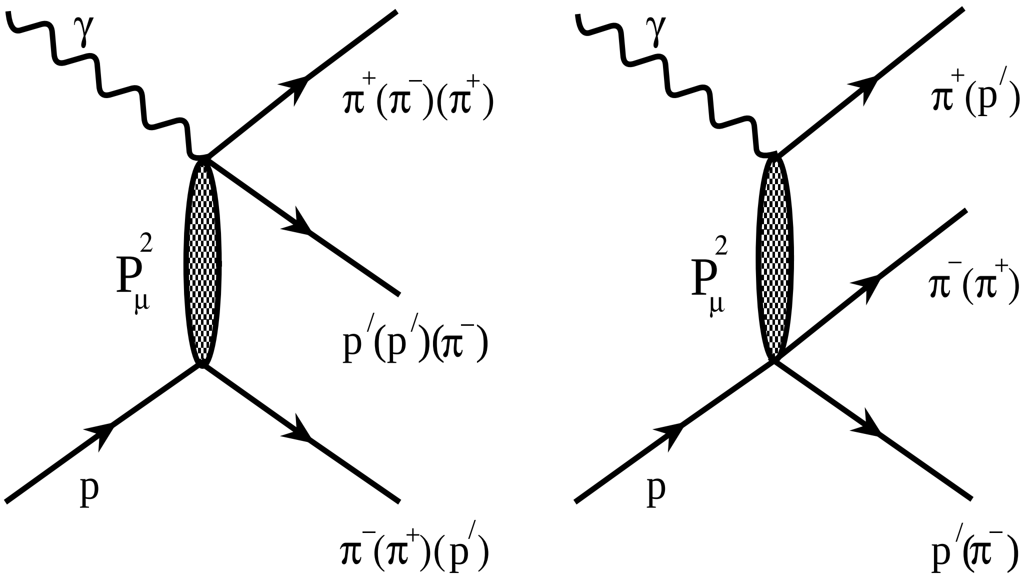
——— **exchange processes, shown in the slide # 26**

·········· 3-body phase space

——— **contribution from direct 2π production, described by diagrams in slide # 26**



Direct 2π production mechanisms derived from the CLAS data on the final hadron invariant masses and π^- angular distributions



The amplitudes were parameterized as:

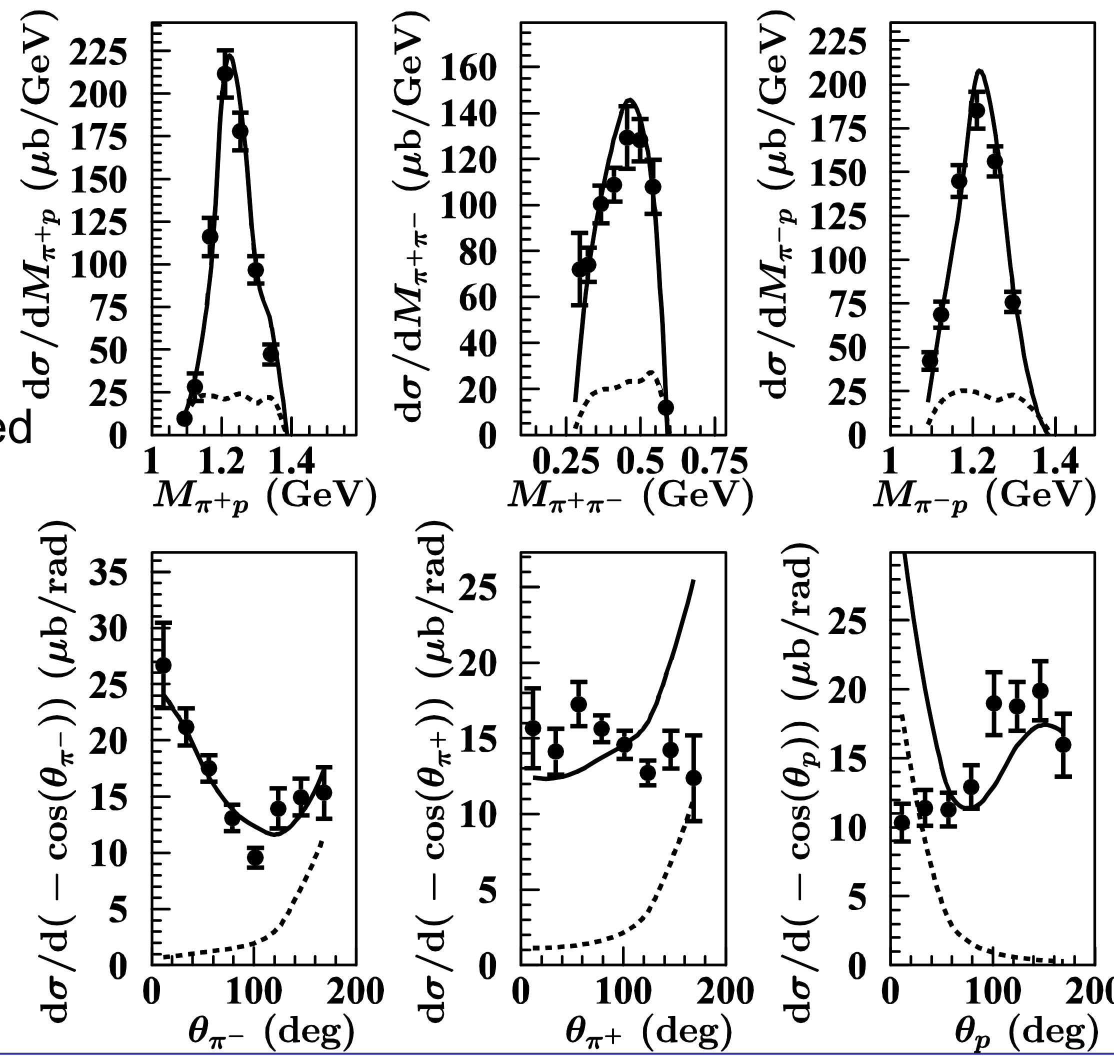
$$M_d = A(W, Q^2)\varepsilon_\mu^\gamma \overline{U}_{p'}\gamma_\mu U_p \frac{1}{W^4} e^{b(P_\mu^2 - P_{\mu\,\min}^2)}(P_1 P_2)$$

Description of invariant mass and angular distributions with direct 2π production mechanisms shown in the slide #26

—— full

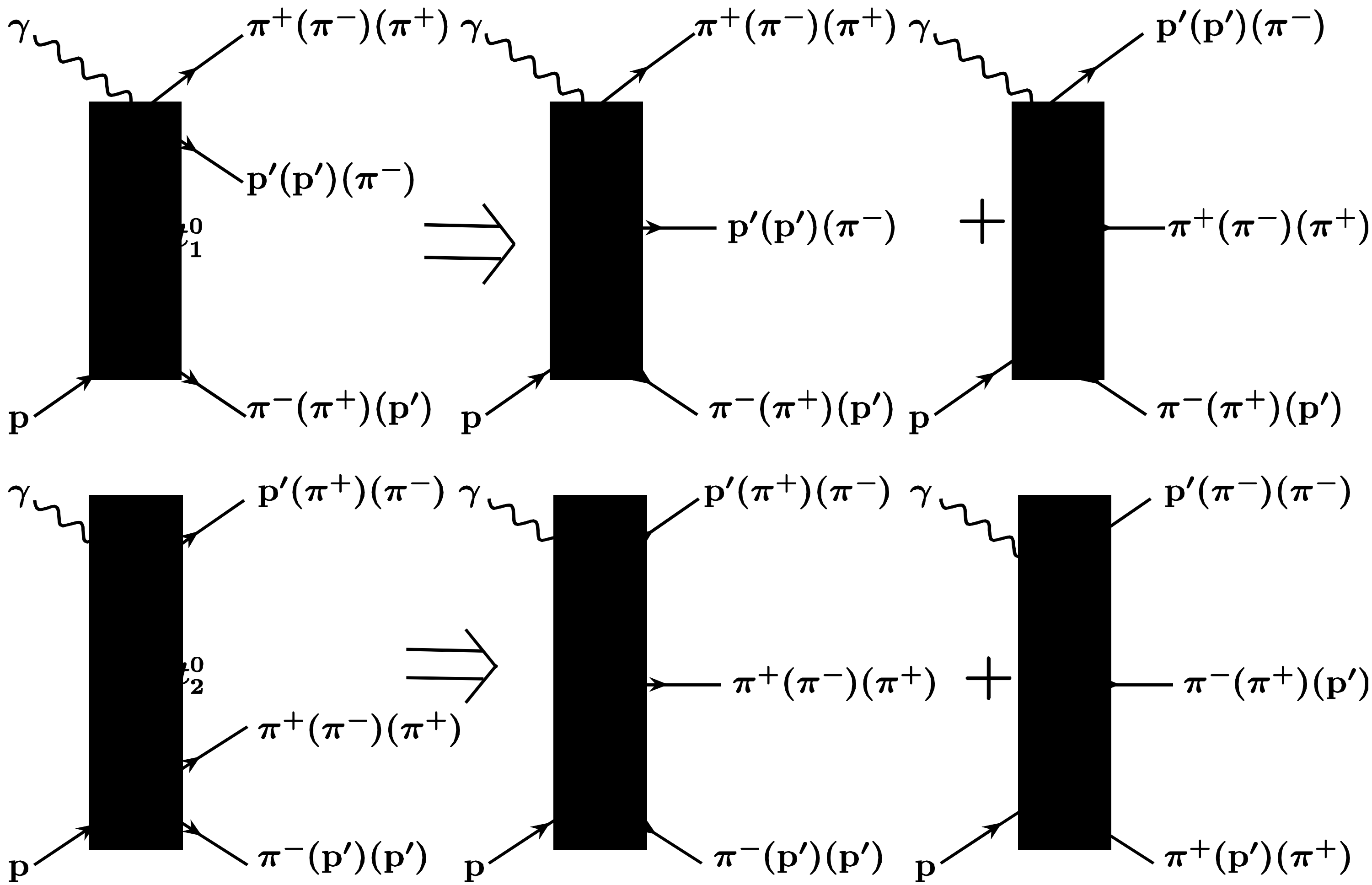
- - - 2π direct

The π^+p, $\pi^-\pi^+$, π^-p mass and π^- angular distributions were described successfully

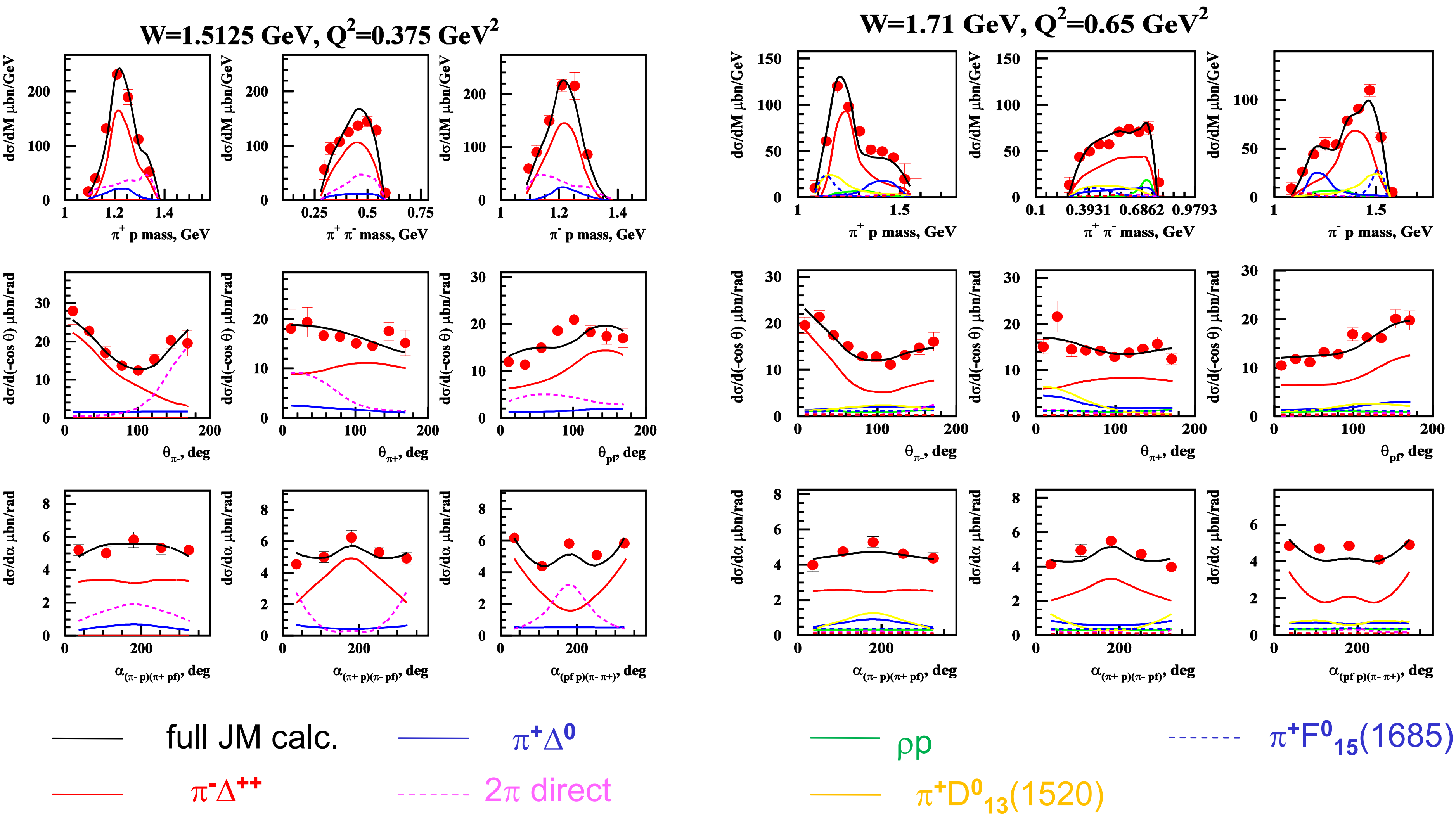


Failure in description of π^+ and proton angular distributions, revealed necessity to modify direct 2π production mechanisms.

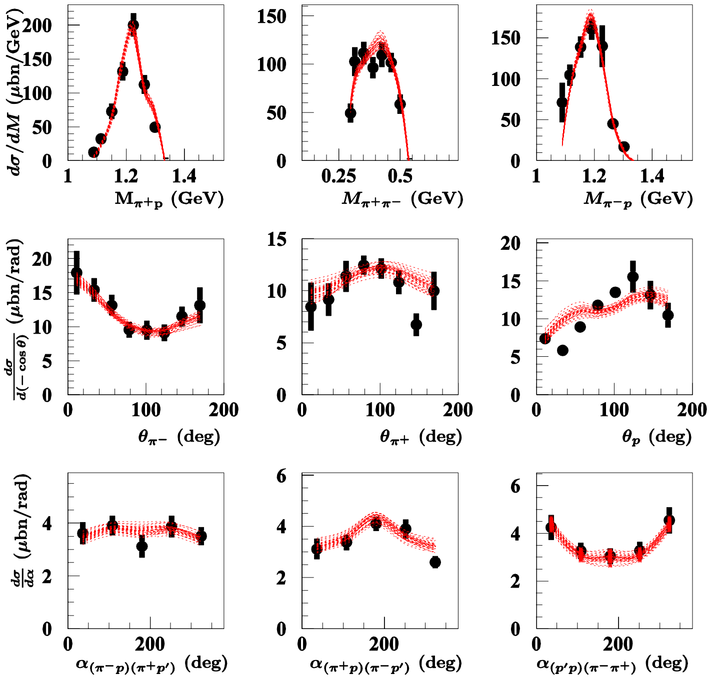
Direct 2π production mechanisms determined from analysis of all available CLAS data on Nππ electroproduction

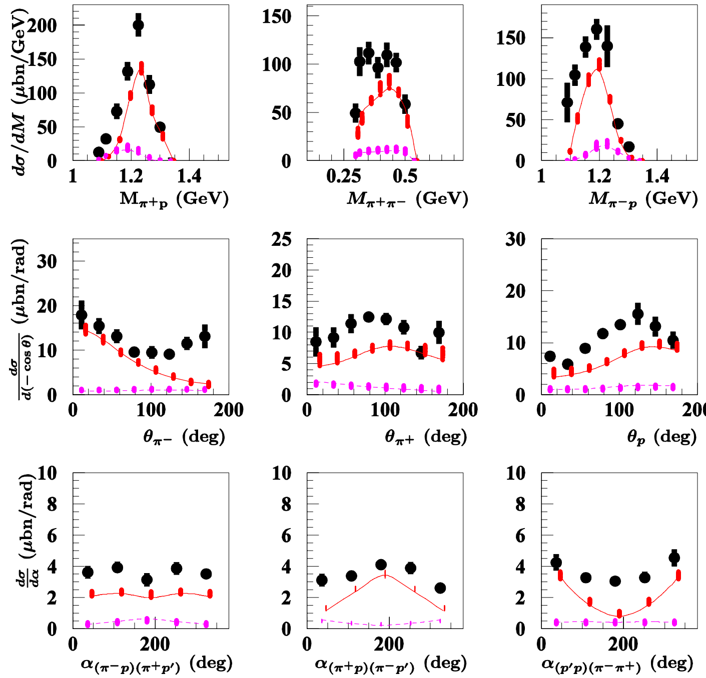


Description of the CLAS Nππ differential cross sections within the framework of JM model



Cross sections for contributing isobar channels derived from the Nππ CLAS data fit, that can be used for reaction model development





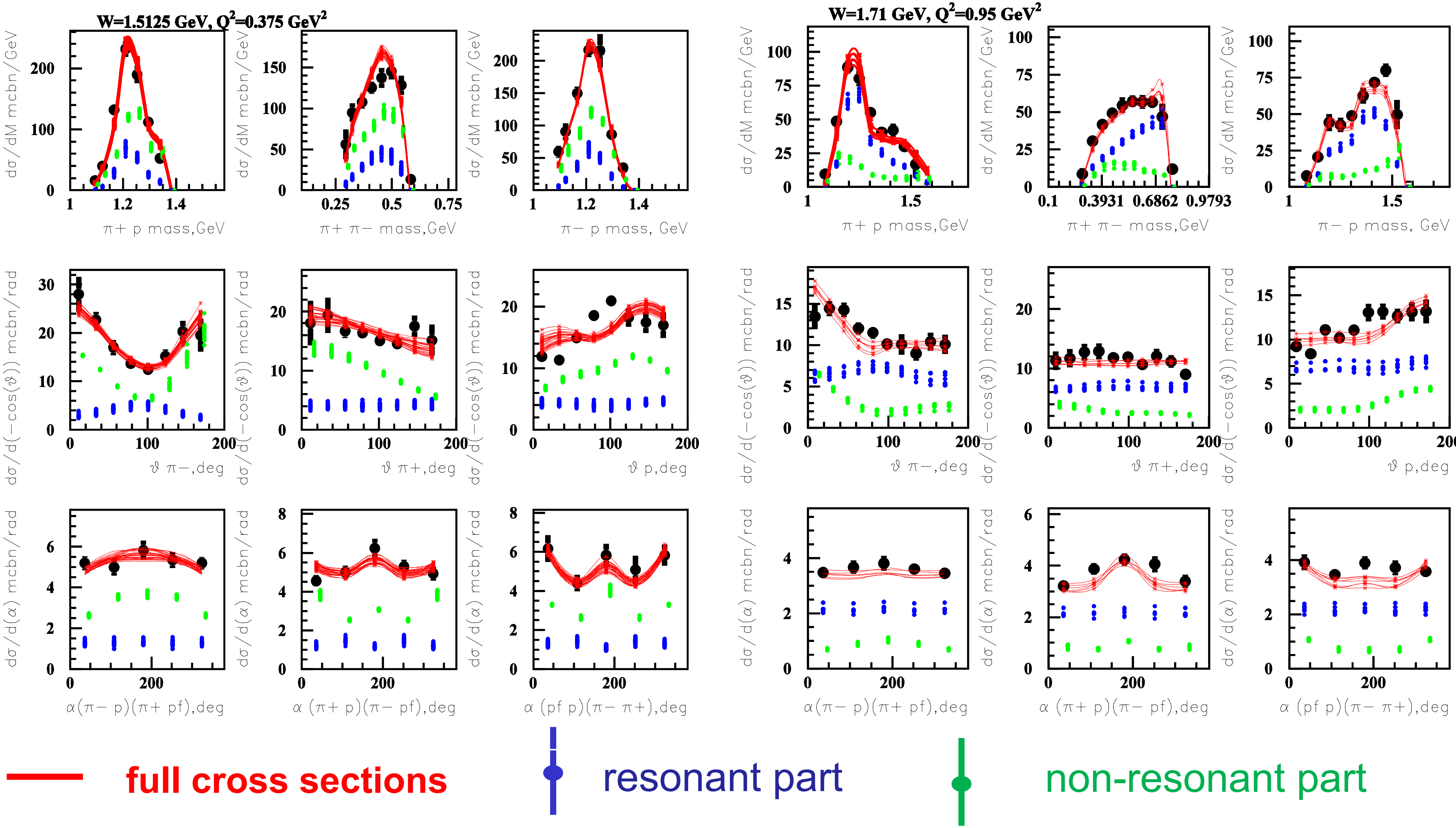
band of differential cross sections calculated in JM model that are closest to experimental Nππ data, being determined under requirement : χ^2/d.p.< χ^2/d.p._max

differential cross sections for contributing isobar channels:

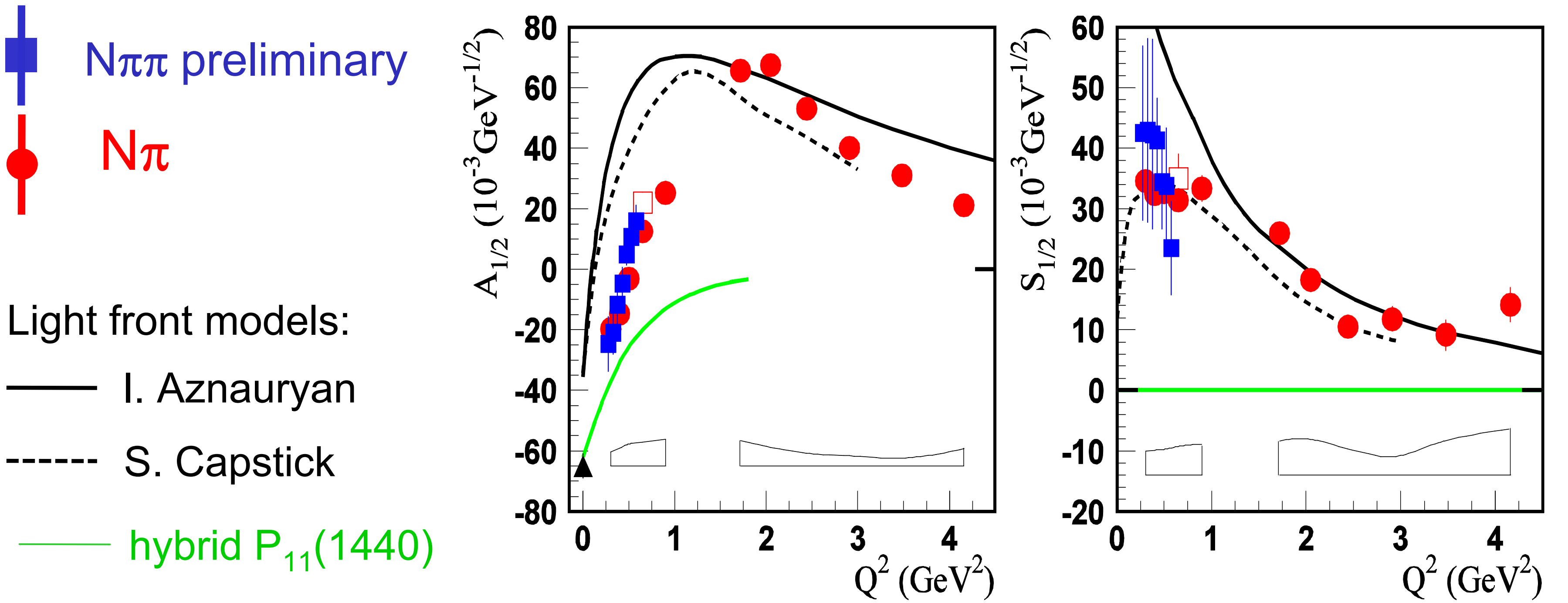
$\pi^-\Delta^{++}$

$\pi^+\Delta^0$

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

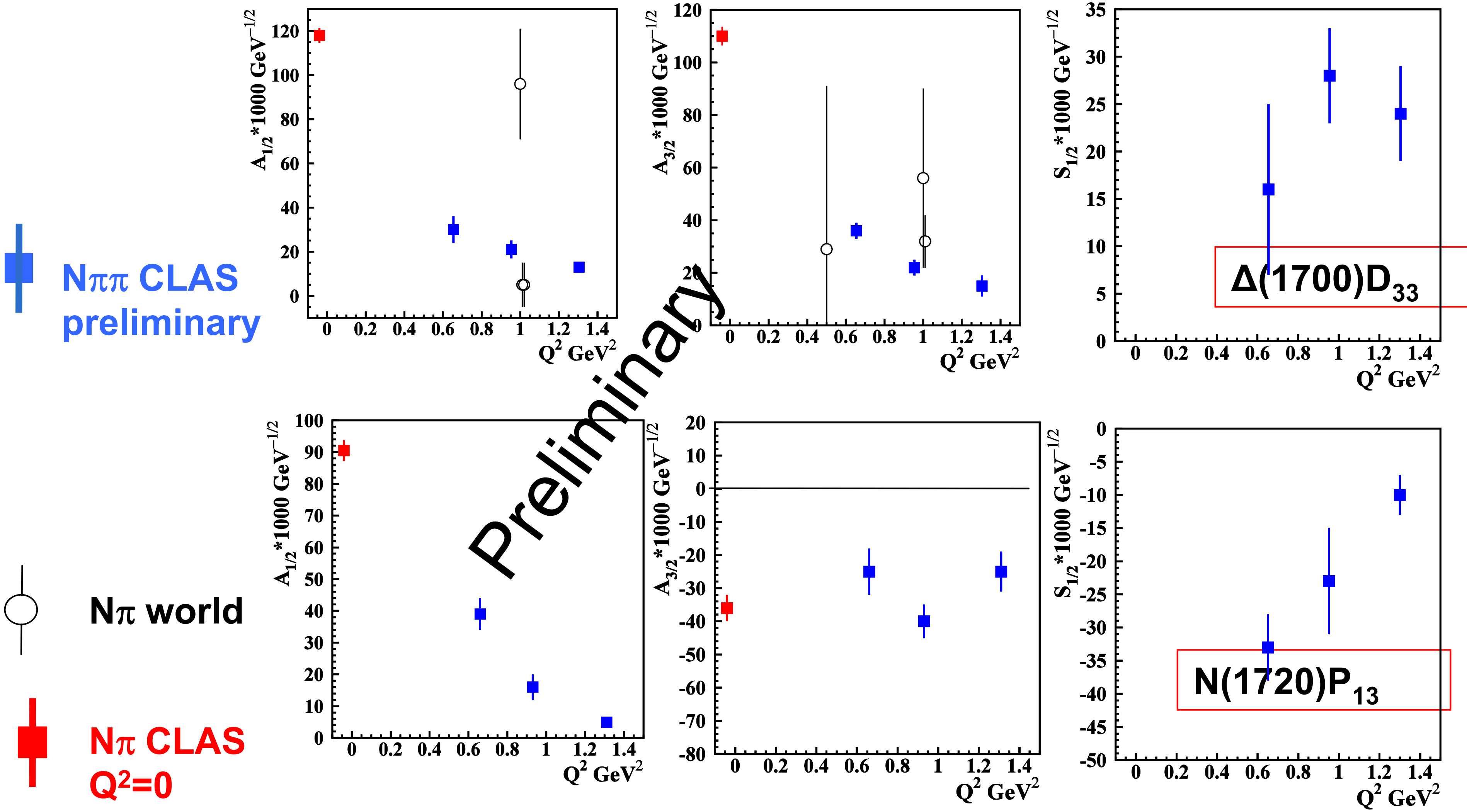


P_{11}(1440) electrocouplings from the CLAS data on $N\pi/N\pi\pi$ electroproduction



- Good ***agreement*** between the electrocouplings obtained from the ***$N\pi$ and $N\pi\pi$ channels***: Reliable measure 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***.
- ***Zero crossing for the $A_{1/2}$*** amplitude has been observed for the first time, indicating the importance of light-front dynamics.

High lying resonance electrocouplings from Nππ CLAS data analysis



Extension of reaction models for $N\pi\pi$ electroproduction into kinematic area of $3.0<Q^2<12$ GeV^2

- Analysis of the available CLAS $N\pi\pi$ data clearly demonstrated our capabilities to establish all relevant mechanisms from their manifestation in various observables, offering reliable separation between resonant/ non-resonant processes, if the contribution of mechanisms described at the level of phenomenological parameterization to fully integrated cross sections is < 30 %.

- Substantial part of $N\pi\pi$ cross sections should be described implementing relevant diagram explicitly. It makes problematic to utilize meson-baryon diagrams with typical cut-off parameters Λ~ 1.0 GeV for description of $N\pi\pi$ electroproduction at Q^2>5.0 GeV2. The models accounting for relevant quark degrees of freedom looks attractive for description of $N\pi\pi$ electroproduction in N* excitation region at these distance scales.

Request for modeling of non-resonant $N\pi\pi$ amplitudes at high Q^2

- Evaluate the prospects of describing non-resonant $N\pi\pi$ amplitudes at $1.1<W<2.0$ GeV and $3.0<Q^2<12$ GeV^2 employing effective quark degrees of freedom for a major isobar channel:

  $\gamma_v p \rightarrow \pi^- \Delta^{++}$

- Study possibilities to implement quark degrees of freedom in description of non-resonant amplitudes in isobar channels with smaller cross sections:

  $\gamma_v p \rightarrow \rho p$

  $\gamma_v p \rightarrow \pi^+ D_{13}^0(1520)$

Back-up

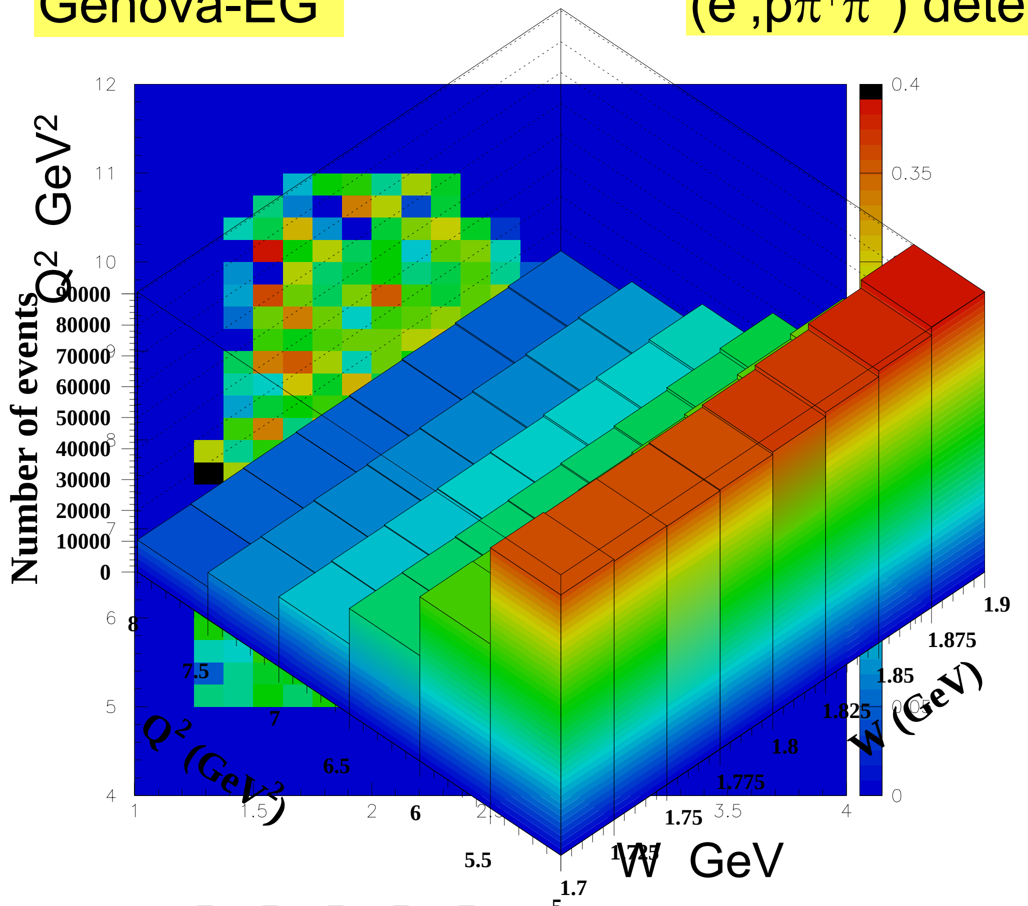
Kinematic Coverage of CLAS12

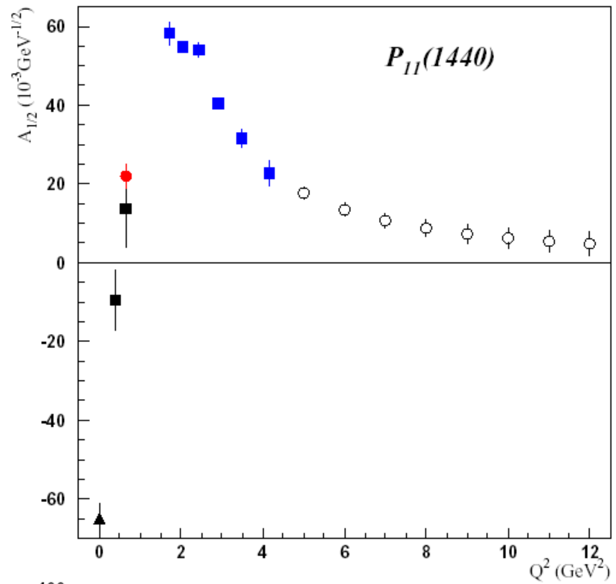
60 days

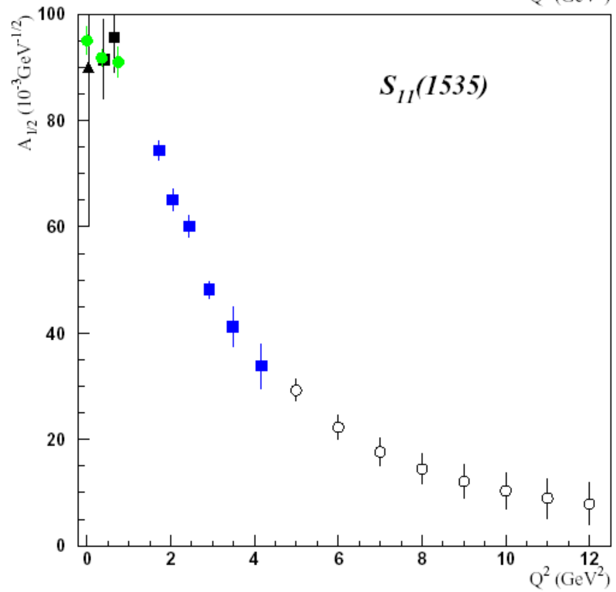
L= 10^{35} cm^{-2} sec^{-1}, ΔW = 0.025 GeV, ΔQ^2 = 0.5 GeV^2

Genova-EG

(e',p$\pi^+\pi^-$) detected







Ground state and P11(1440) electrocouplings & quark model expectations

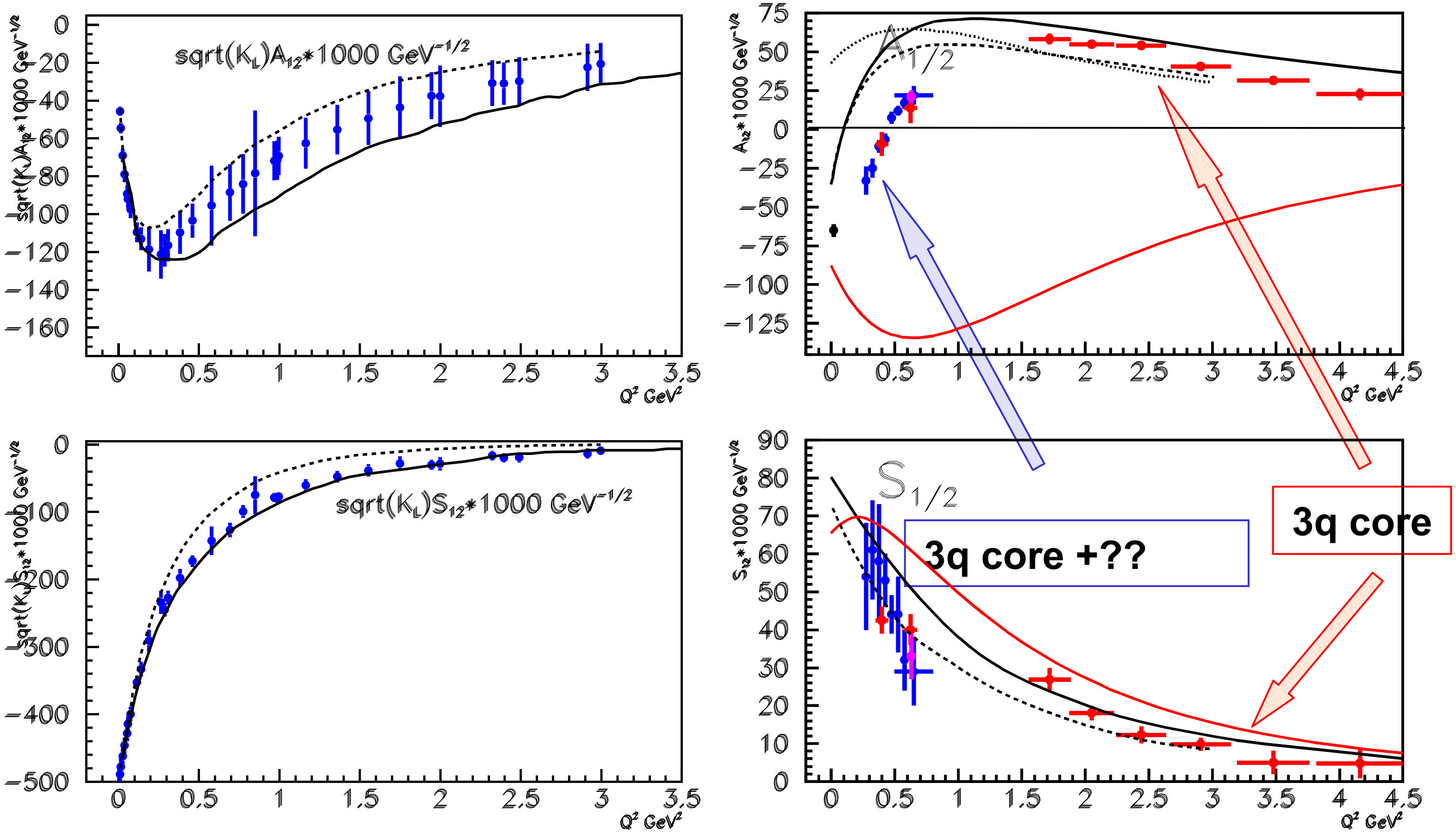
Ground p state | P11(1440)

--------- S.Capstick light cone (LC) model

.... B.Metsch Bethe-Salpeter model

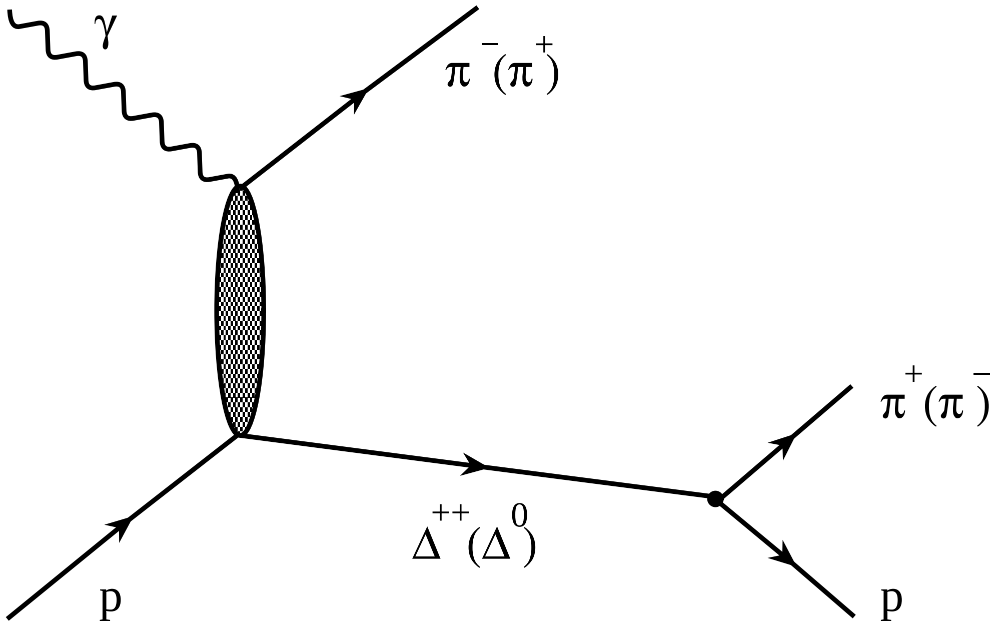
——— I.Aznauryan LC model

——— M.Giannini/ E.Santopinto hyper-centric CQM



P11(1440) electrocouplings at Q^2>2.0 GeV^2 are consistent with substantial contribution from 3-quarks in first radial excitation, while at Q^2<0.6 GeV^2 additional contributions become evident.

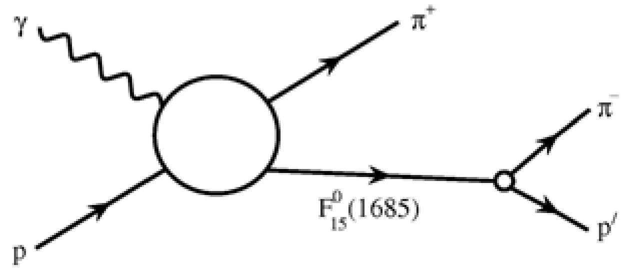
An additional contact terms in πΔ channels needed to fit data.



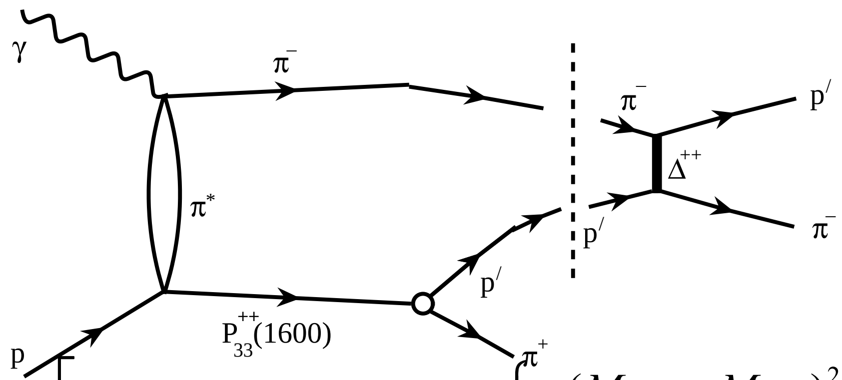
$$M_t = (A(W)\varepsilon_\mu^\gamma \overline{U}_{\Delta_\nu}\gamma^\mu U_p P_\pi^\nu + B(W)\varepsilon_\nu^\gamma \overline{U}_{\Delta_\nu}\gamma^\mu U_p (2P_\pi^\mu - P_\gamma^\mu))$$

$$\bullet \frac{1}{t-\Lambda^2} \qquad \Lambda^2 = 1.64\ \mathrm{GeV}^2 \qquad t = (P_\gamma - P_\pi)^2$$

The amplitudes for $\gamma p \rightarrow \pi^+ F^0_{15}(1685)$ and $\gamma p \rightarrow \pi^- P^{++}_{33}(1600)$ channels.



$$M = A(W,Q^2) \bullet \left[\varepsilon^{\gamma}_{\mu} \overline{U}_{p'} \gamma^{\mu} U_p (P_{F15} \bullet P_{\pi^+}) \bullet \exp\left\{ -\frac{(M_{\pi^- p} - M_{F15})^2}{\Gamma^2_{F15}} \right\} \right]$$



$$M = A(W,Q^2) \bullet \left[\varepsilon^{\gamma}_{\mu} \overline{U}_{p'} \gamma^{\mu} U_p \frac{1}{t - m^2_{\pi*}} \bullet \exp\left\{ -\frac{(M_{\pi^- p} - M_{P33})^2}{\Gamma^2_{P33}} \right\} \bullet \frac{1}{P_{p'} P_{\pi^-}} \right]$$

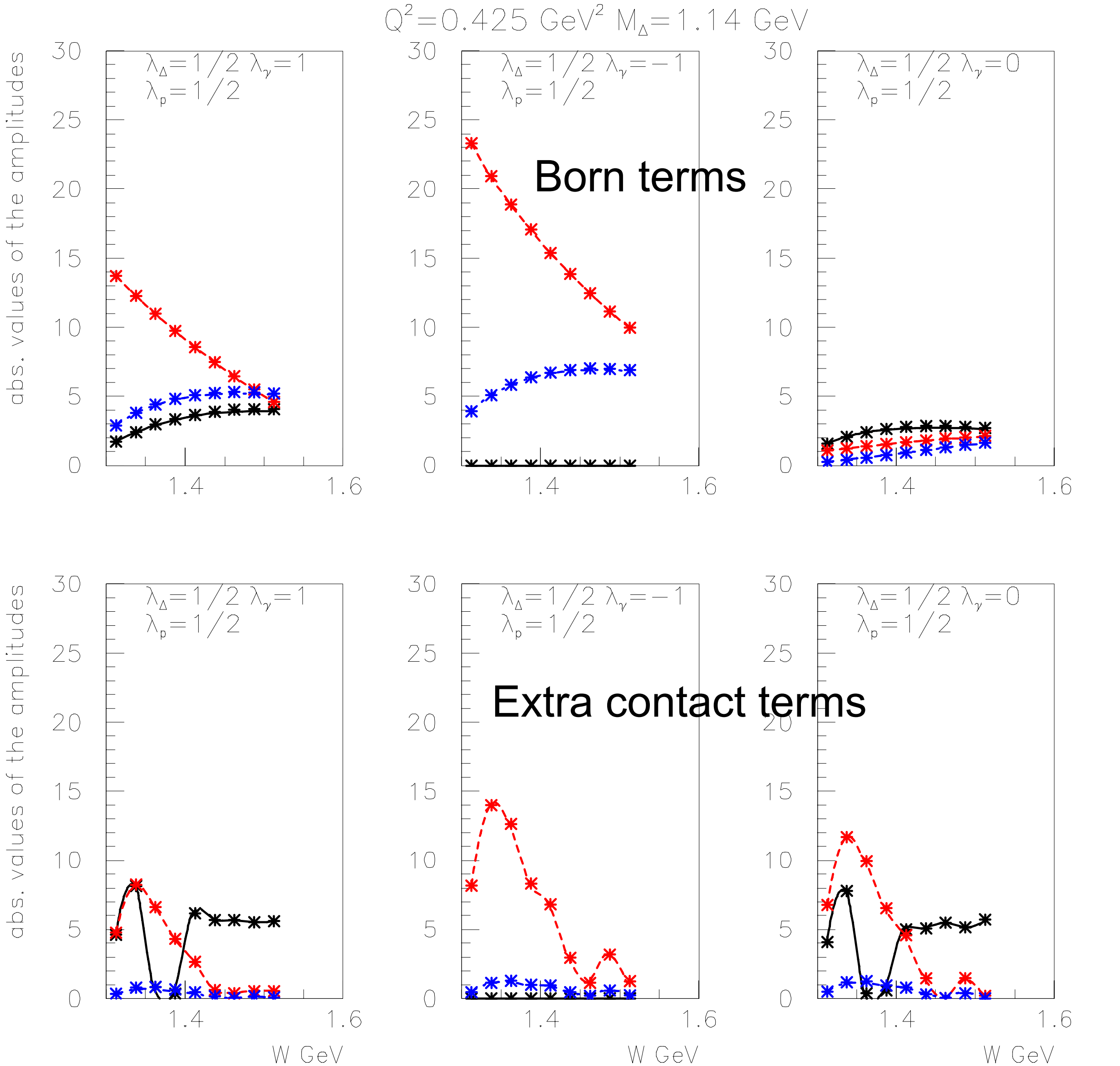
Input for Nπ/Nππ coupled channel analysis : partial waves of total spin J for non-resonant helicity amplitudes in $\pi^-\Delta^{++}$ isobar channel

J

- **1/2** (black)
- **3/2** (red)
- **5/2** (blue)

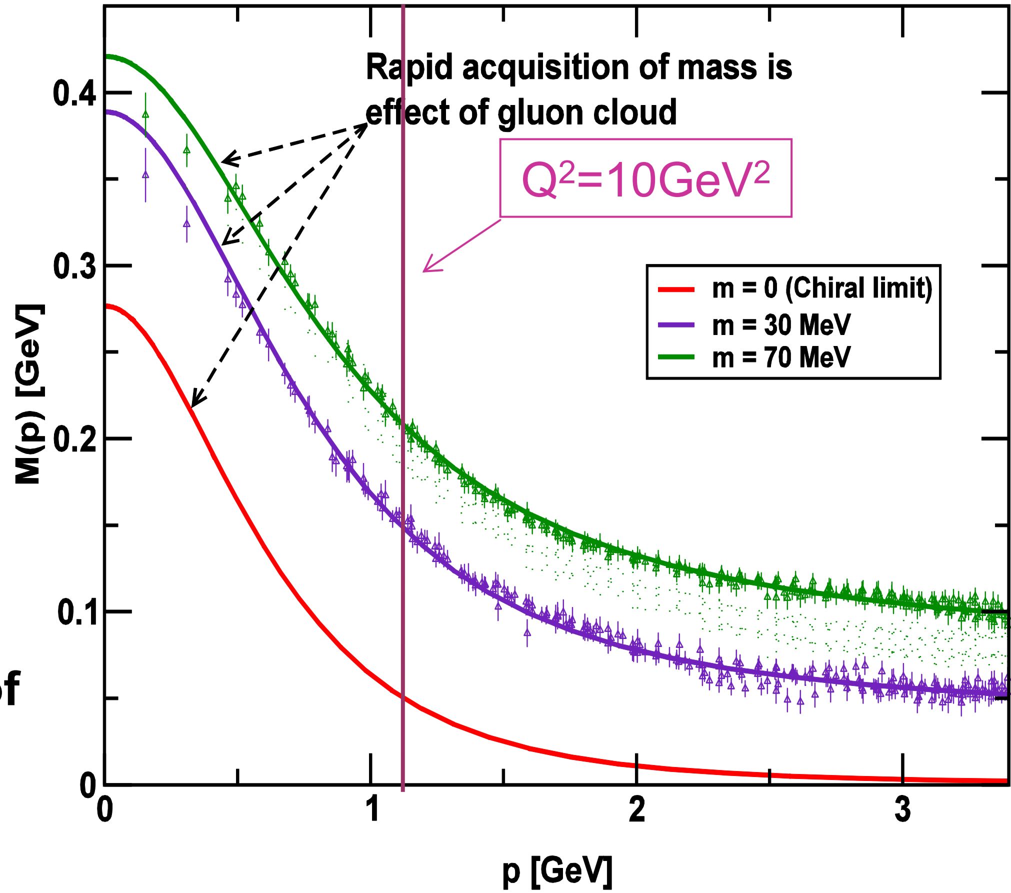
$$\langle \lambda_f | T^J | \lambda_\gamma \lambda_p \rangle = \int \frac{2J+1}{2} \langle \lambda_f | T | \lambda_\gamma \lambda_p \rangle \bullet d^J_{\mu\nu}(\theta_f)\sin\theta_f \, d\theta_f$$

Will be used for N* studies in coupled channel approach developing by EBAC.



Physics objectives in the N* studies with CLAS12

- **explore the interactions between the dressed quarks, which are responsible for the formation for both ground and excited nucleon states.**
- **probe the mechanisms of light current quark dressing, which is responsible for >97% of nucleon mass.**



Approaches for theoretical analysis of N* electrocouplings: LQCD, DSE, relativistic quark models. See details in the White Paper of EmNN* JLAB Workshop, October 13-15, 2008: http://www.jlab.org/~mokeev/white_paper/

DSE: lines and LQCD: triangles

Q^2 = 10 GeV^2 = (p times number of quarks)^2= 10 GeV$^2 \rightarrow$ p = 1.05 GeV

Parallel sessions #9,13 of GHP09 Workshop