Nucleon resonance studies in collaboration between SINP at MSU and Hall B at Jefferson Lab

Presented by V.I.Mokeev

Hall-B/SINP Collaboration:

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E.L.Isupov, K.Stopani,
N.V.Shvedunov.

V.D.Burkert, V.I.Mokeev, R.Gothe,
L.Elouadrhiri, D.Weygand. K.Joo.

Primary objectives in N* studies with CLAS

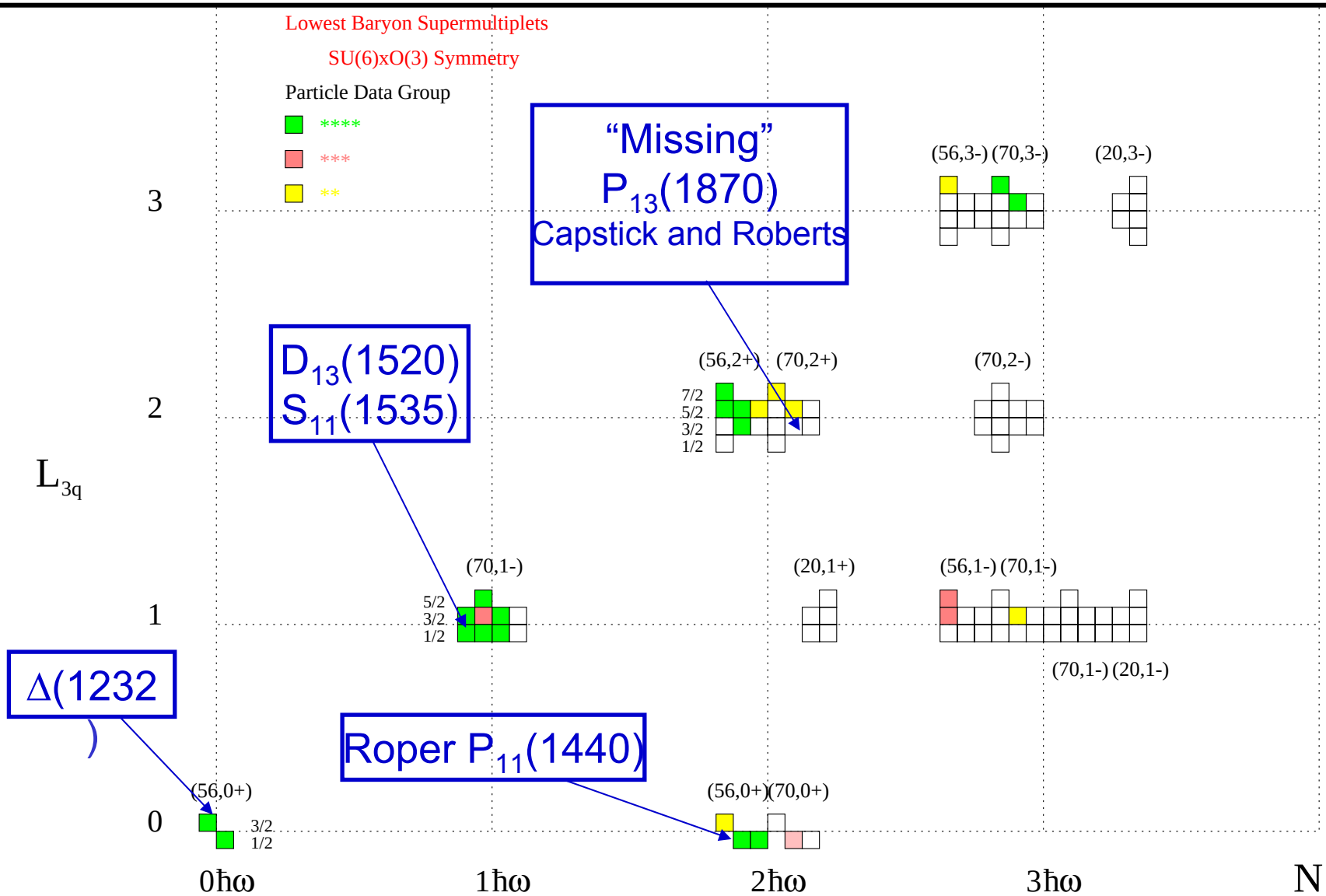
Our experimental program seeks to determine

- N-N* transition helicity amplitudes (electrocouplings) at photon virtualities $0.2 < Q^2 < 5.0$ GeV^2 for almost all excited proton states from analyzing various meson electro- production channels

- Studies of N* spectrum (masses,spin/parities,hadronic decays) in meson photo- and electro- production with primary objective of searching for so called “missing” baryon states

OEPVAYa group is actively involved in both major directions of the N* Program with CLAS detector.

SU(6)xO(3) Classification of Baryons



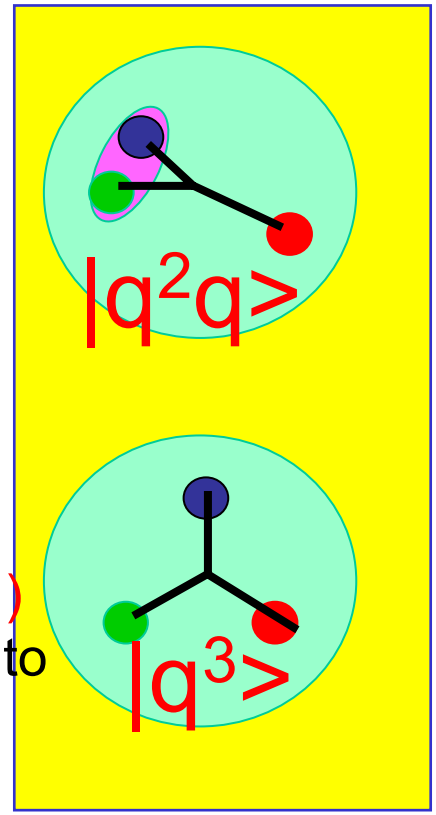
"Missing" Baryon States

Quark models with underlying SU(6)xO(3) symmetry predict many states, not observed in either hadronic experiments or in meson photo- and electro-production.

Possible solutions:

1.states don't exist, e.g. di-quark, DSE models predicts fewer states. Part of expected N*'s can not be created because of qq-correlation or final size of quarks

2. exist but have not been found.



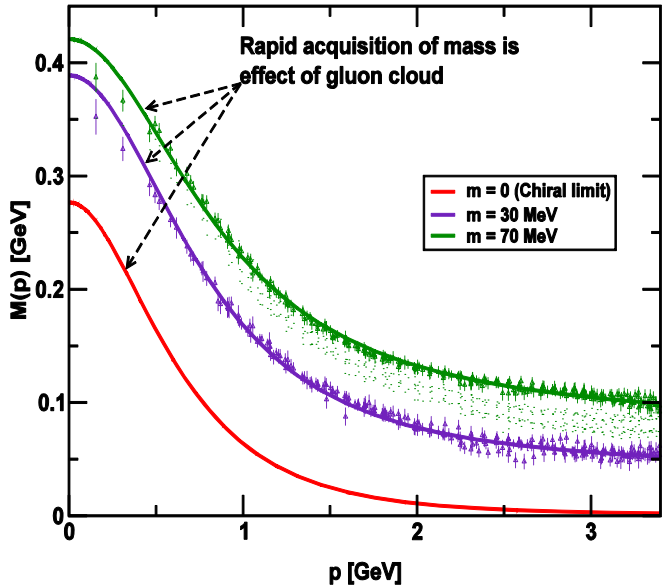
Possible reason: they decouple from π N-channel.

Model expectations: Hadronic couplings to $N\pi$ π (Δ π, $N\rho$) much larger, while photocouplings are more comparable to those for observed states.

Other channels sensitive to "missing" states are: $K\Lambda$, $K\Sigma$, $p\omega$

Dressed quark properties and transition from non-perturbative to perturbative regimes of strong interactions

- ~few MeV current quark mass is approached at asymptotically high momentum p running over quark
- sharp mass evolution at p<2.0 GeV reflects transition between non-perturbative/perturbative regime of strong interaction
- directly related to long range behavior of the QCD β–function
- >98% of nucleon mass comes from dynamical dressing of current quarks

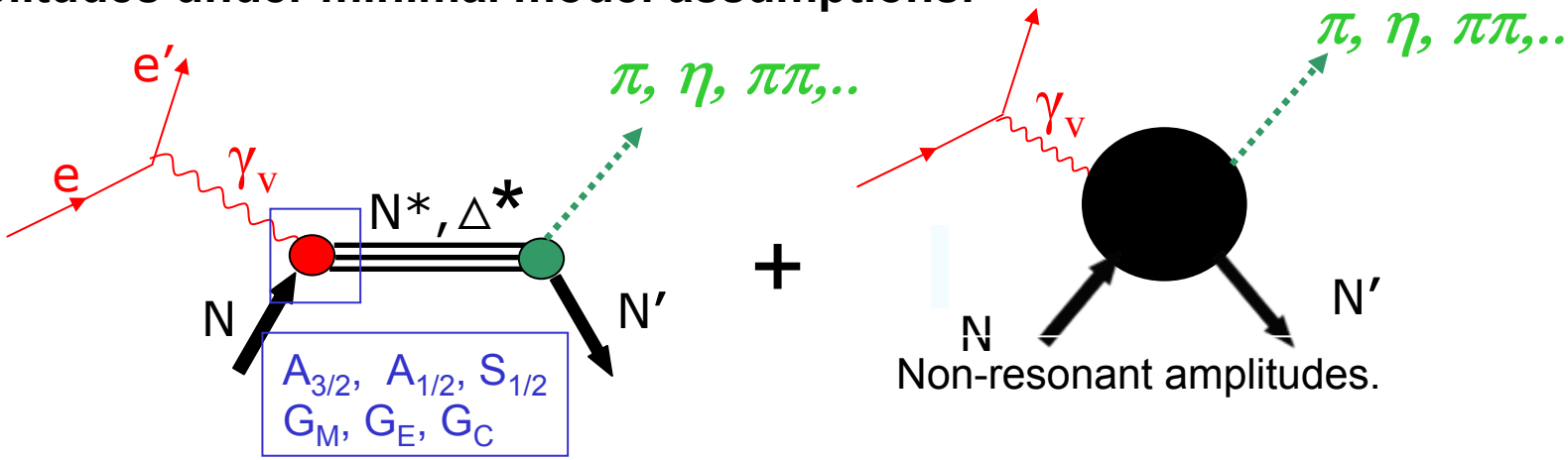


The studies of the ground and excited nucleon state structure allow us to access properties and interactions of dressed quarks at various distance scales

Key part in the studies of quark confinement in baryons!

How N* electrocouplings can be accessed

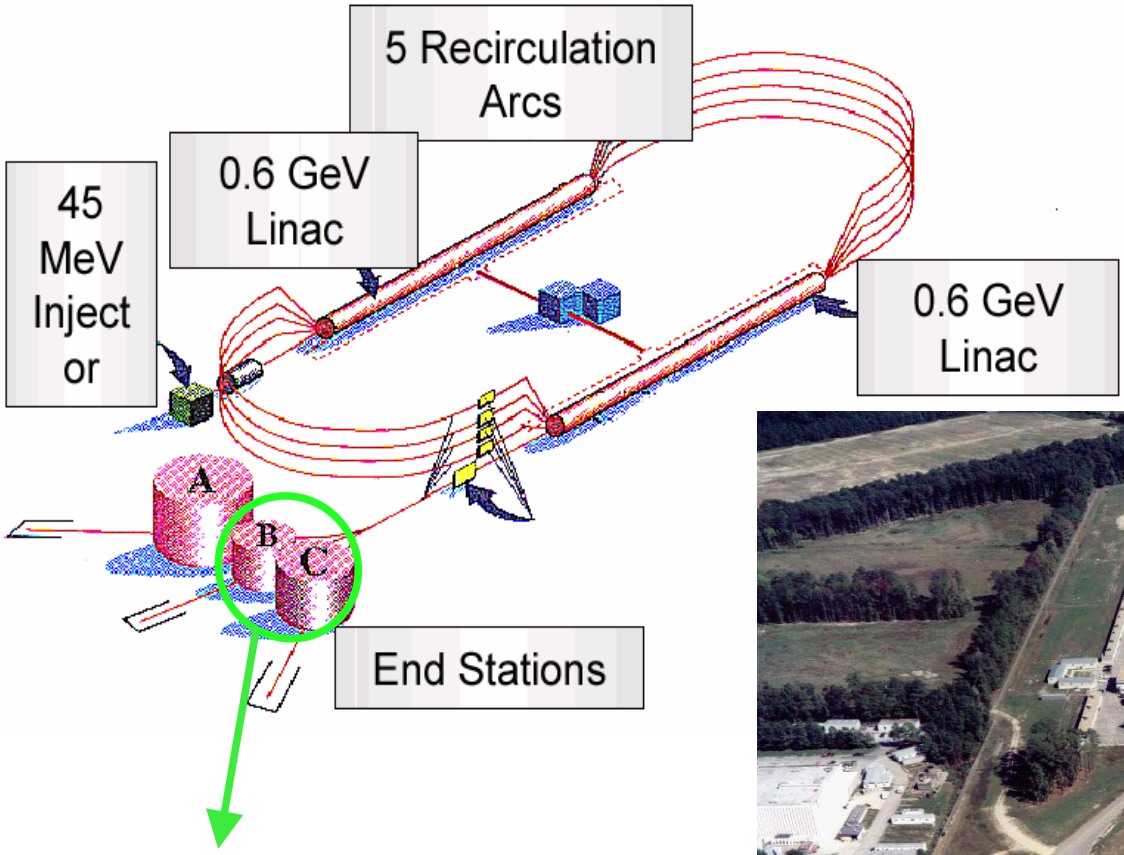
- **Isolate the resonant part of production amplitudes by fitting the measured observables within the framework of reaction models, which are rigorously tested against data.**
- **N* electrocouplings can then be determined from resonant amplitudes under minimal model assumptions.**



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]

Ускоритель электронов непрерывного действия в Jefferson Lab – CEBAF



CLAS

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

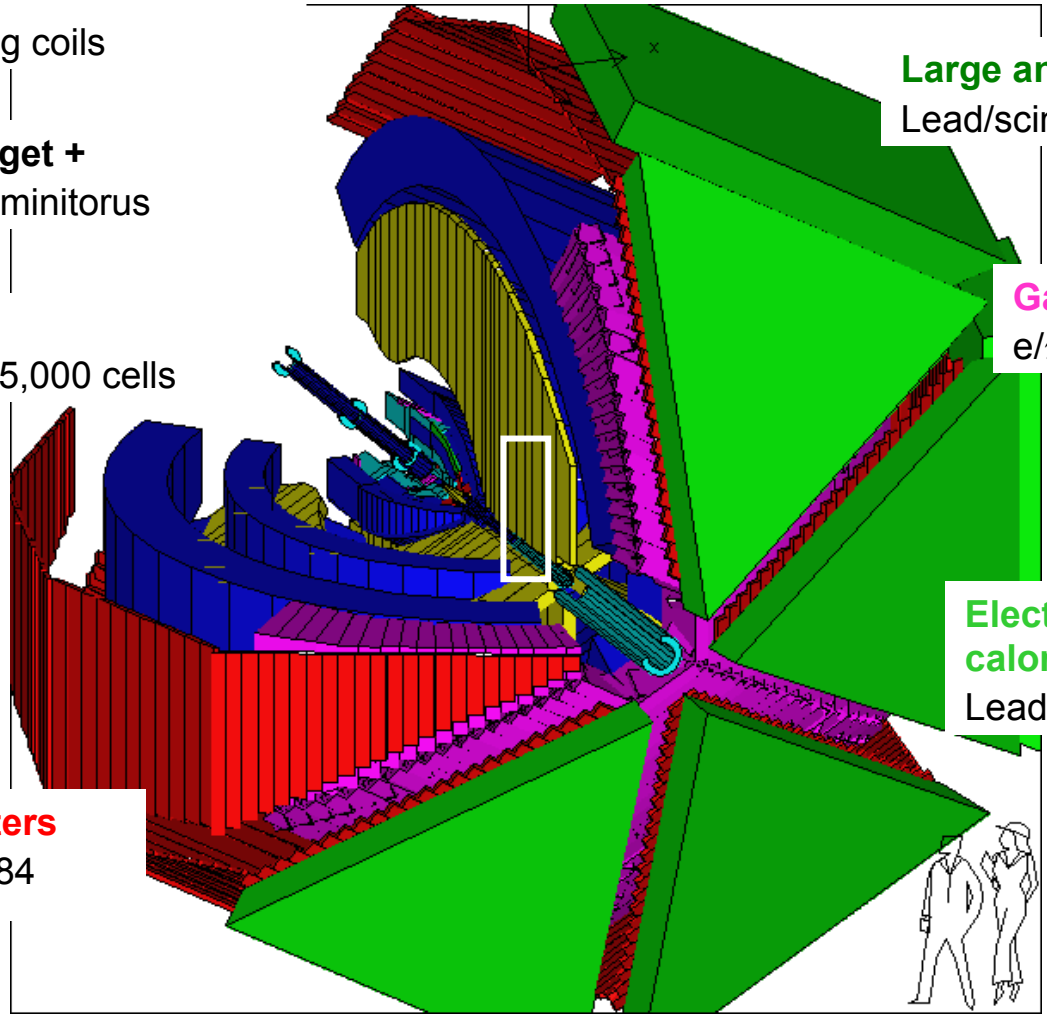
CEBAF Large Acceptance Spectrometer

Torus magnet
6 superconducting coils

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

Drift chambers
argon/CO_2 gas, 35,000 cells

Time-of-flight counters
plastic scintillators, 684 PMTs



Large angle calorimeters
Lead/scintillator, 512 PMTs

Gas Cherenkov counters
e/π separation, 216 PMTs

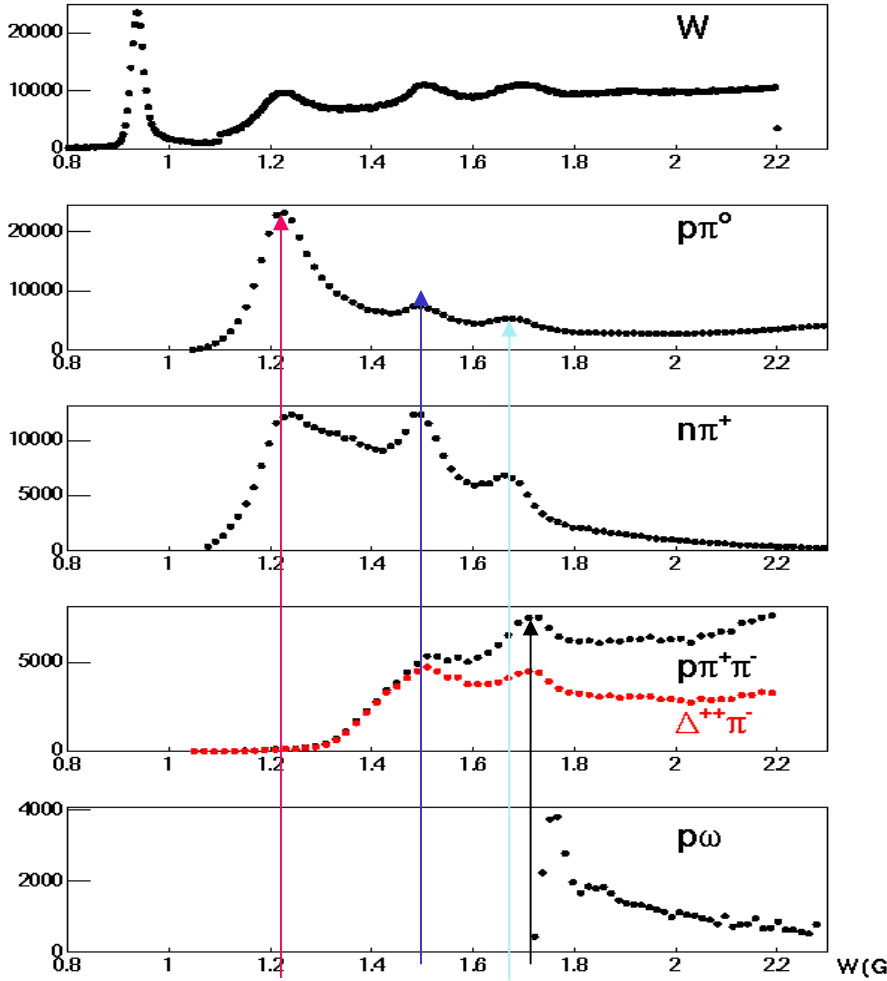
Electromagnetic calorimeters
Lead/scintillator, 1296 PMTs

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 $K\Sigma$.**

Therefore knowledge on $N\pi/N\pi\pi$ electro production mechanisms is key for the entire N* Program

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



HallB/SINP results on the studies of $ep \rightarrow e'p\,\pi^+\pi^-$ exclusive channel with CLAS

Измерения сечений выполнены в 2 сеансах в кинематических областях:

1.31 < W < 1.56 ГэВ
$0.2 < Q^2 < 0.6$ ГэВ^2 $\Delta Q^2=0.05$ ГэВ^2 **G.V.Fedotov-** G. Fedotov *et al.*, PRC
120000 отобранных событий 79,015204 (2009)

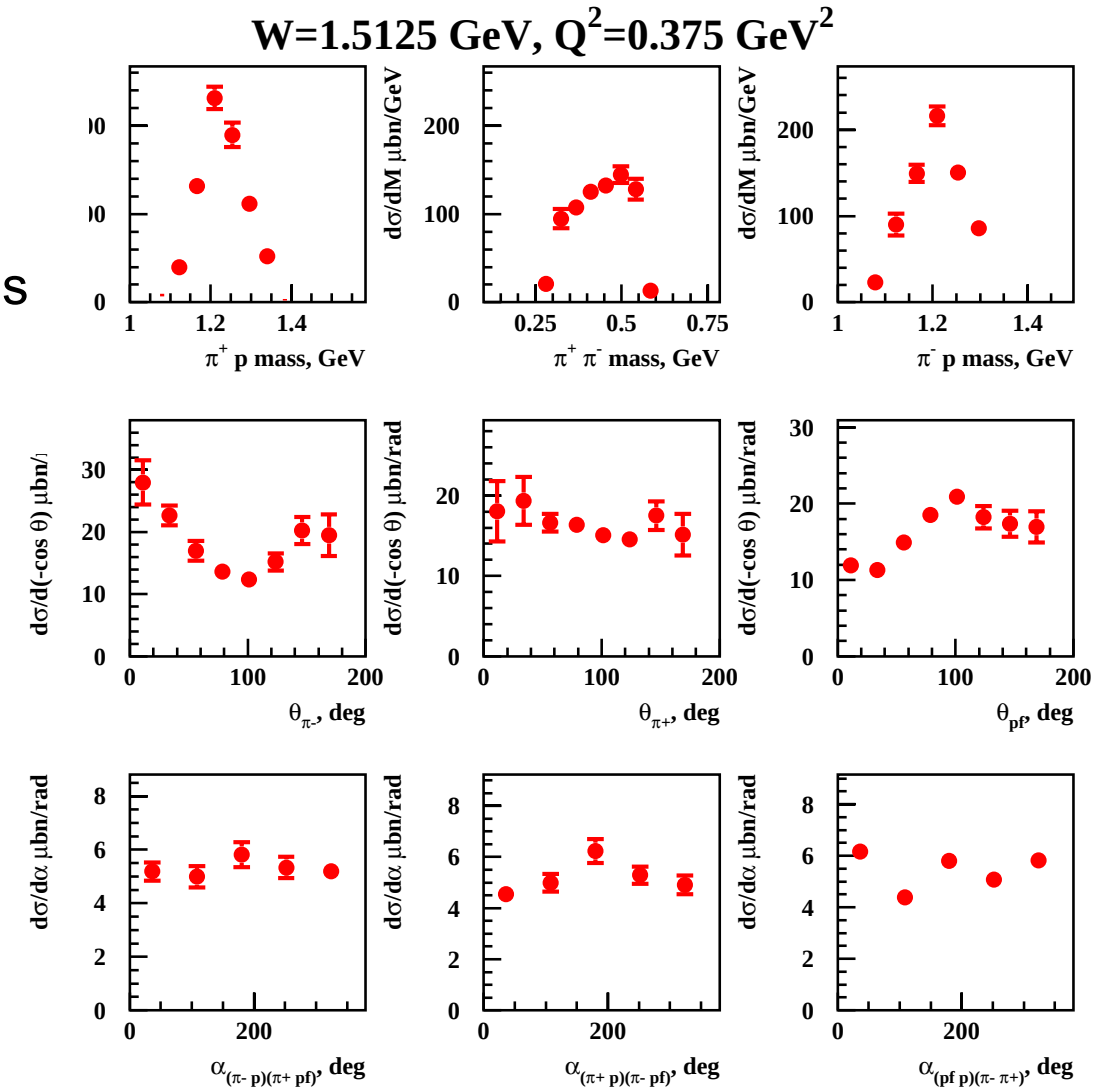
1.41 < W < 2.10 ГэВ
$0.5 < Q^2 < 1.5$ ГэВ^2 $\Delta Q^2=0.3$ ГэВ^2 **E.N.Golovach -**M. Ripani *et al.*,
150000 отобранных событий PRL 91,022002 (2003)

$\Delta W=25$ MeV
$\Delta W/W<2\%$

> 10000 точек измеренных сечений реакции $ep \rightarrow e'p\,\pi^+\pi^-$

Nππ CLAS data and JM model

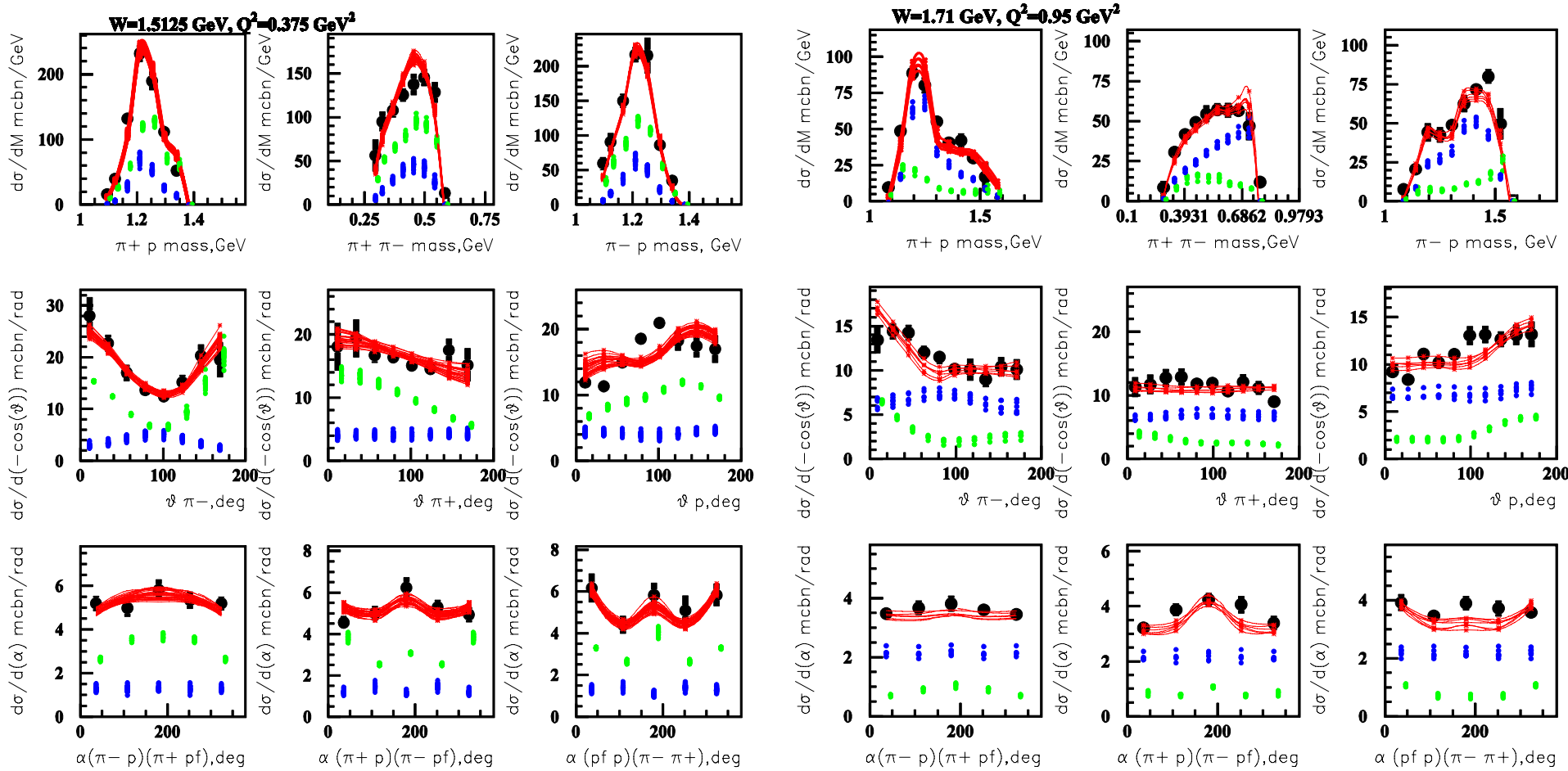
The measurements with an unpolarized e^- beam onto a proton target offer nine independent differential cross sections in each (W, Q^2) bin.



Meson-baryon model JM was developed with a primary goal of extracting N* electrocouplings from the fit of all observables:

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

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

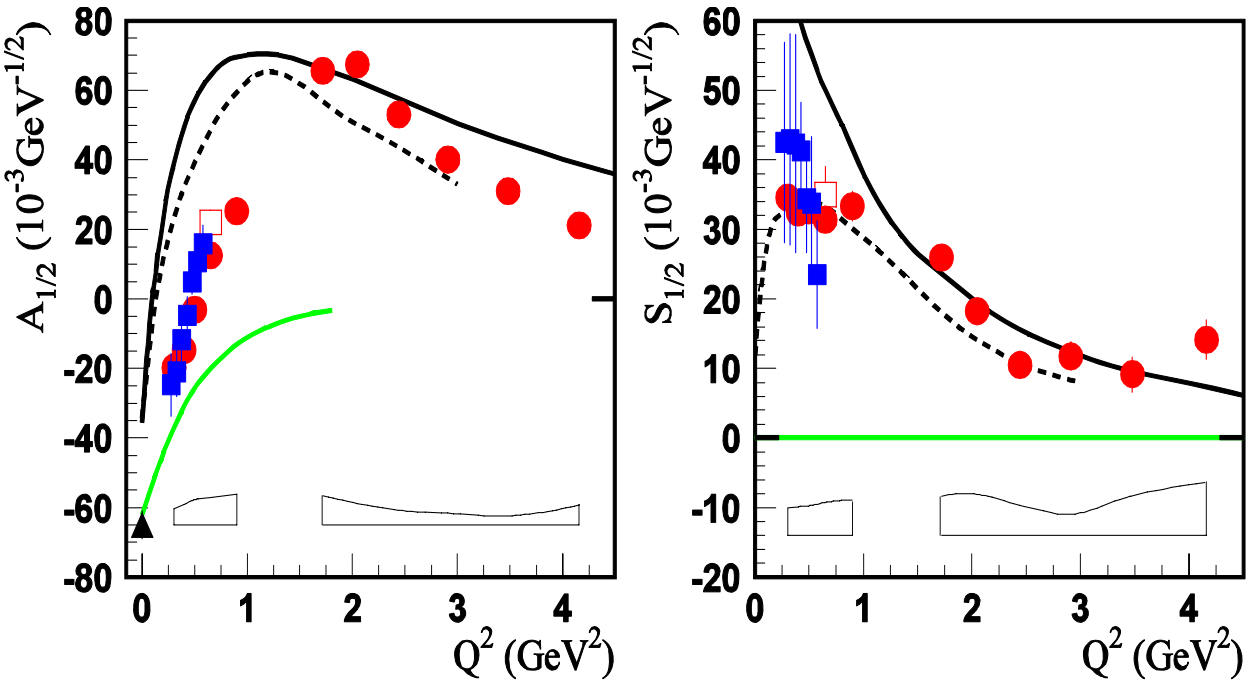
$N\pi$

Light front models:

—— I. Aznauryan

------ S. Capstick

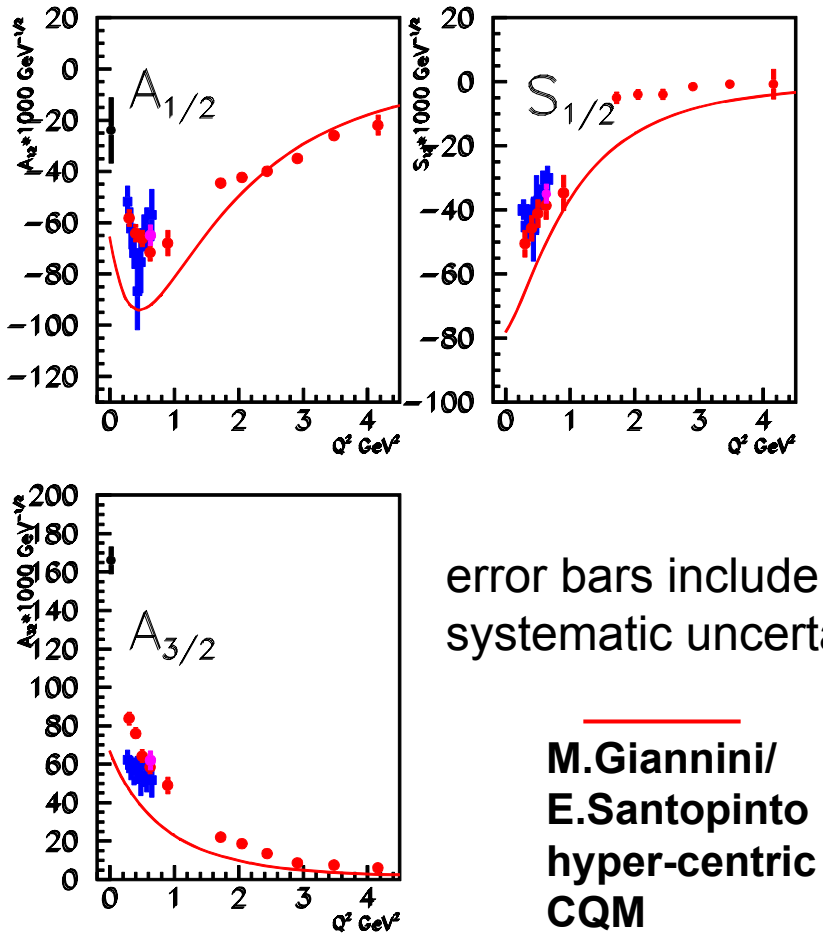
—— hybrid $P_{11}(1440)$



- **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.**

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

- **hypercentric Consituent Quark Model calculations reasonably describe electrocouplings at $Q^2>2.5$ GeV^2, suggesting that the 3-quark component with L=1 is the primary contribution to the structure of this state at high Q^2.**
- **Electrocouplings of $P_{11}(1440)$ and $D_{13}(1520)$ states can not be described at $Q^2<1.0$ GeV^2 accounting for quark degrees of freedom only. There are additional contributions, that are relevant at low photon virtualities**

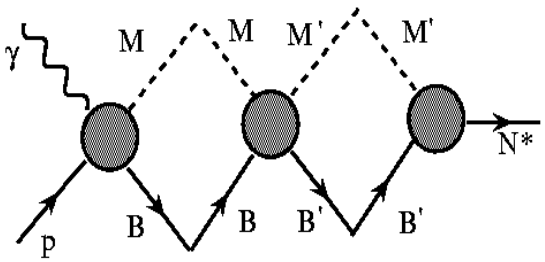


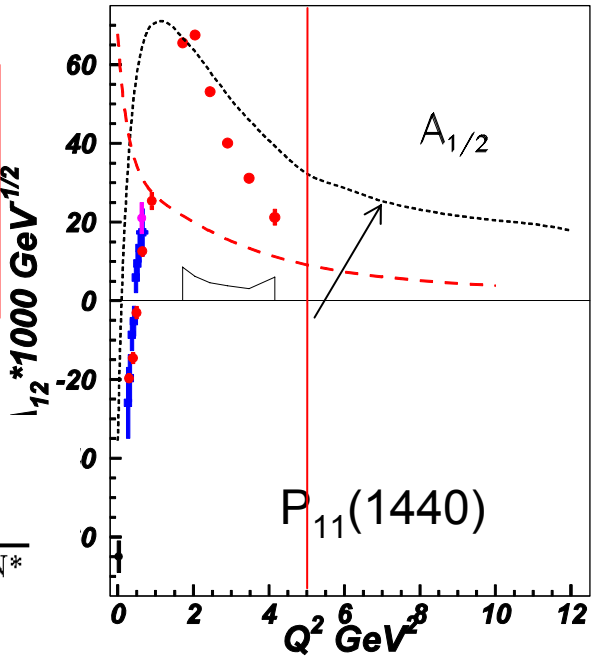
error bars include systematic uncertainties

M.Giannini/ E.Santopinto hyper-centric CQM

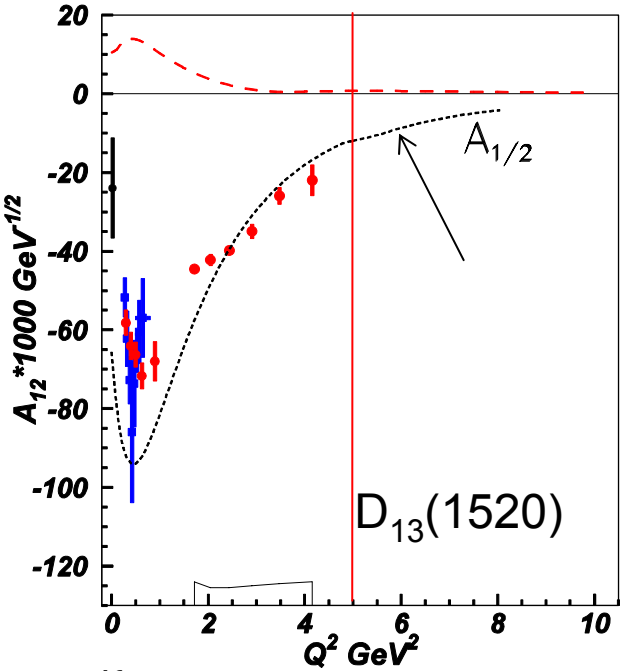
Мезон-барионные и кварковые степени свободы в структуре N*

EBAC: вклады мезон-барионного облака B.Julia-Diaz *et al.*, PRC 76, 5201 (2007).





Кварковая модель на световом конусе. I.Aznauryan



Кварковая модель с гипер-центральным потенциалом. M.Giannini / E.Santopinto

• При Q^2 < 1.5 ГэВ^2 структура N* определяется вкладами как от внутреннего кваркового ядра (r < 0.8ф) так и от внешнего мезон-барионного облака (r > 0.8ф)

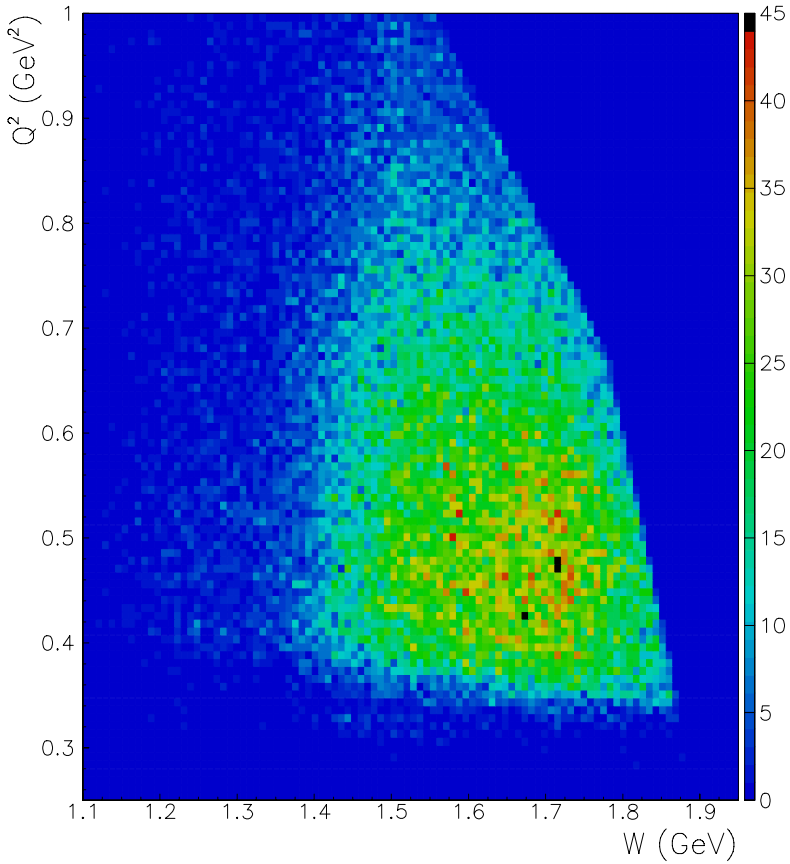
Meson-baryon & quark degrees of freedom for high lying N*'s at $Q^2<1.0$ GeV^2

Analysis of e1e CLAS data on $N\pi\pi$ electroproduction by G.V.Fedotov

$1.4<W<1.8$ GeV

$0.35<Q^2<0.80$ GeV^2

First information on the structure of a major part of N*'s at the distances corresponding to the sizable contributions from both meson-baryon and quark degrees of freedom

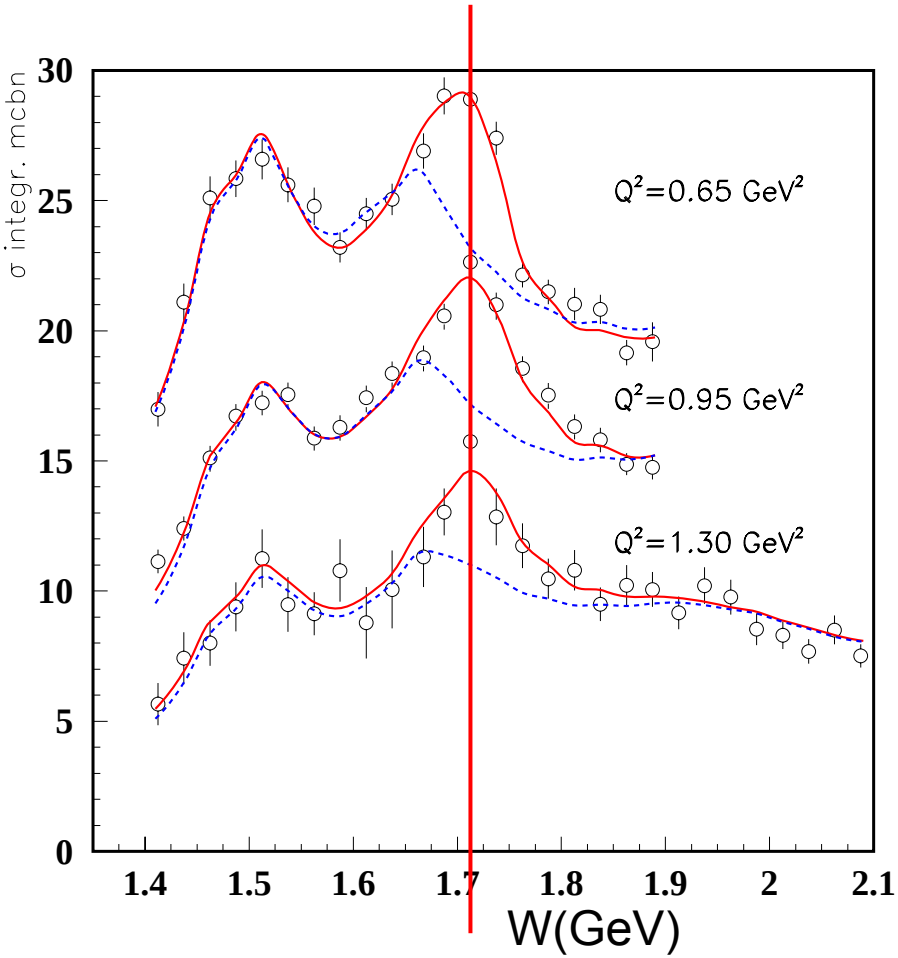


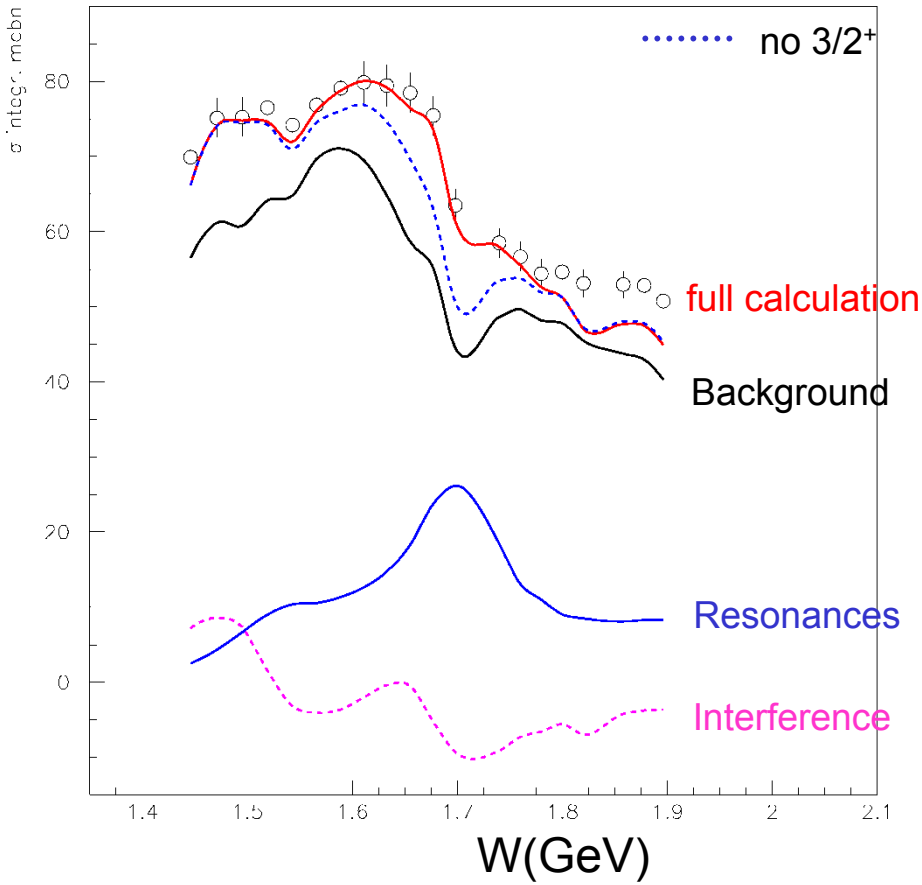
Структура при W~1.7 ГэВ в полных сечениях фото и электророждения пар заряженных пионов из данных CLAS

Электророждение
E.Golovach, M.Ripani

$p\pi^+\pi^-$

Фоторождение

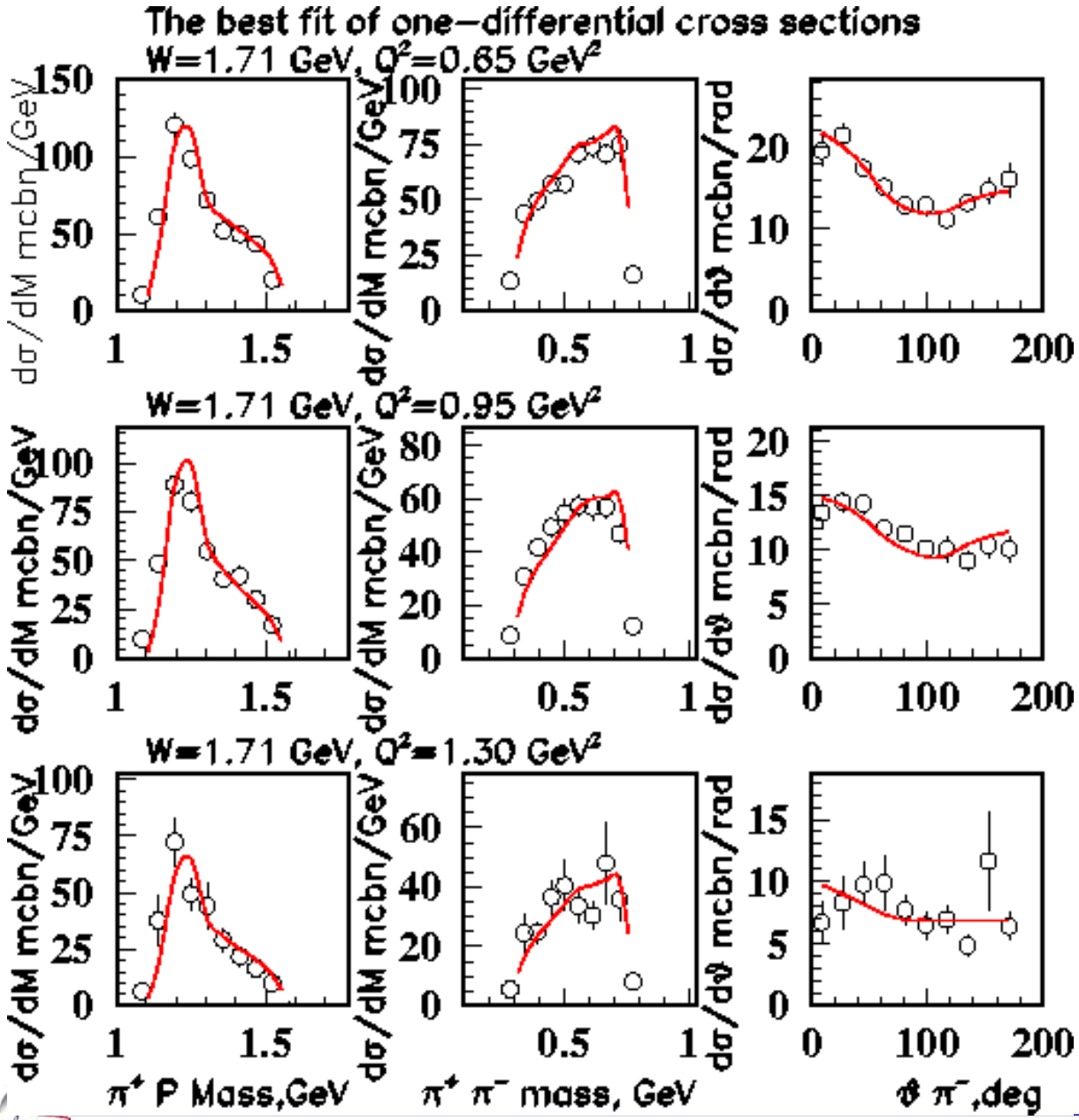




Хорошее описание дифференциальных и интегральных сечений при W~1.7 ГэВ может быть получено:

• предполагая вероятности распадов состояния $P_{13}(1720)$ по каналам $\pi\Delta$ и $\rho\pi$ иным чем установлены в выполненных ранее экспериментах (верхняя и средняя строка таблицы)
• новое барионное состояние $3/2^{+}(1720)$ с квантовыми числами и параметрами адронных распадов, определенными из наилучшего описания данных CLAS (нижняя строка таблицы).

	M, MeV	Γ,MeV	$\Gamma_{\pi\Delta}/\Gamma$, %	$\Gamma_{\rho P}/\Gamma$, %
modified $P_{13}(1720)$	1725±20	114±19	60±12	19±9
PDG $P_{13}(1720)$	1650-1750	100-200	absent	70-85
new state $3/2^{+}(1720)$	1720±20	88±17	41±13	17±10

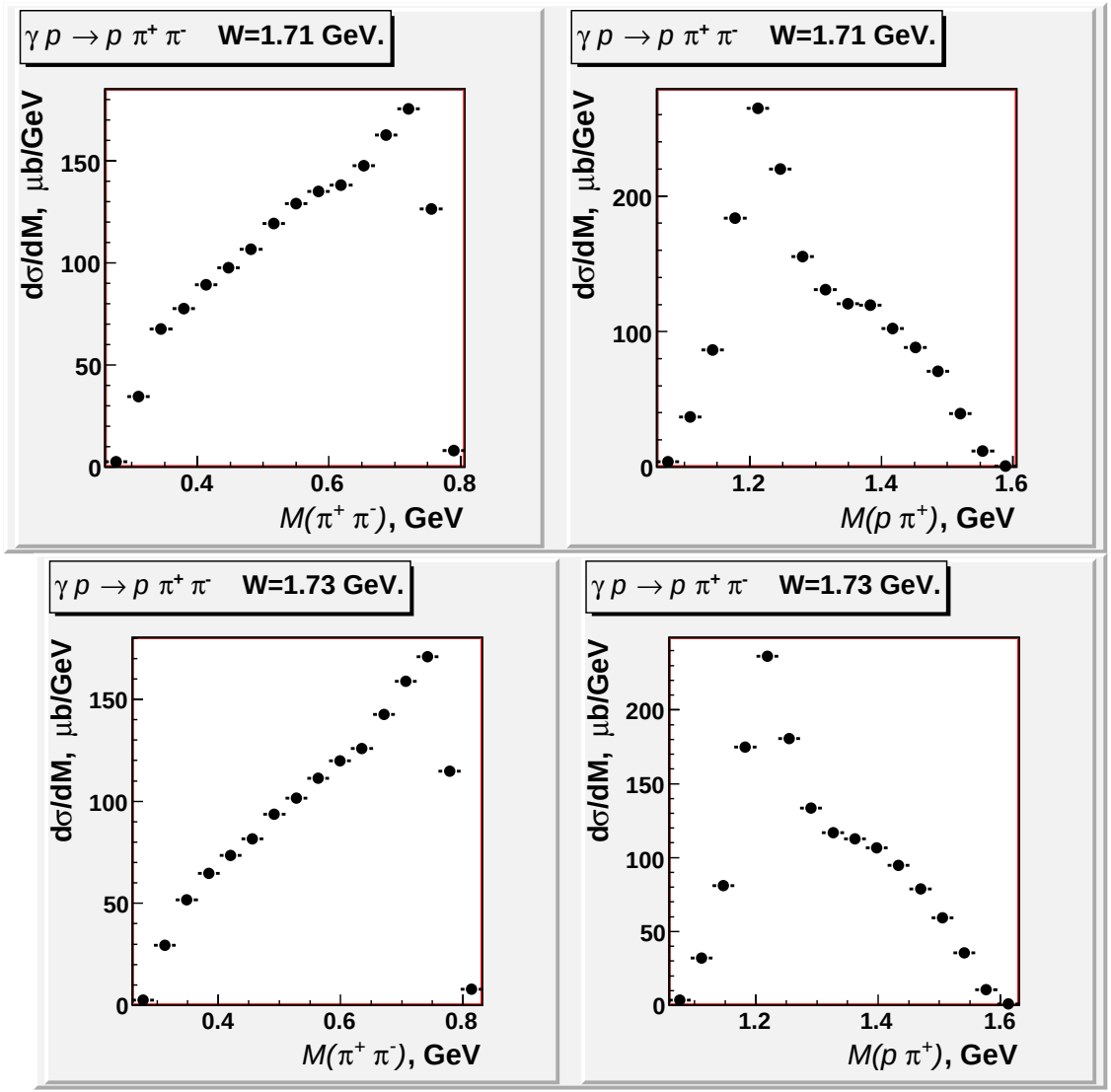

The best fit of one−differential cross sections
W=1.71 GeV, Q²=0.65 GeV²
W=1.71 GeV, Q²=0.95 GeV²
W=1.71 GeV, Q²=1.30 GeV²
dσ/dM mcbn/GeV
dσ/dΦ mcbn/rad
π⁺ P Mass,GeV
π⁺ π⁻ mass, GeV
Φ π⁻,deg

Nππ photoproduction cross sections from the CLAS g11 data. E.N.Golovach.

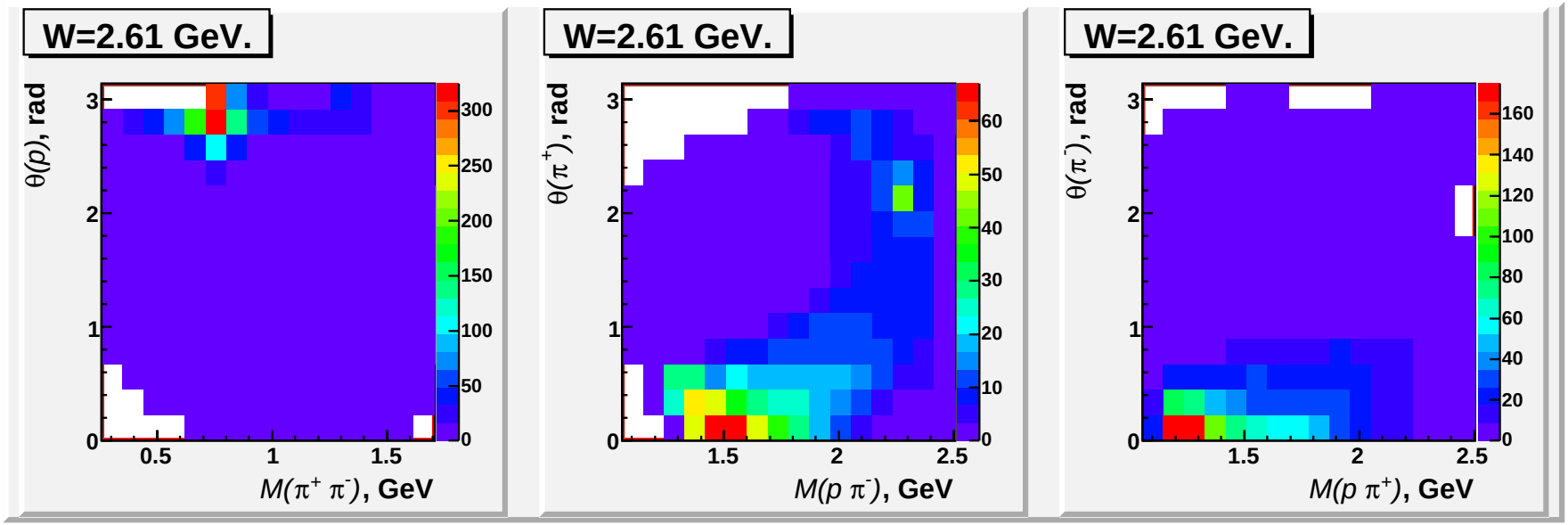
establish an origin of the structure at W=1.7 GeV from combined studies of Nππ photo- and electroproduction

•ρ peaks in Mπ+π– distributions require the contributions from P13(1720) with PDG πΔ and ρp couplings .

•in this scenario the electroproduction data can be described only employing $3/2^+$ (1720) candidate state.



Nππ photoproduction cross sections from the CLAS g11 data. E.N.Golovach.

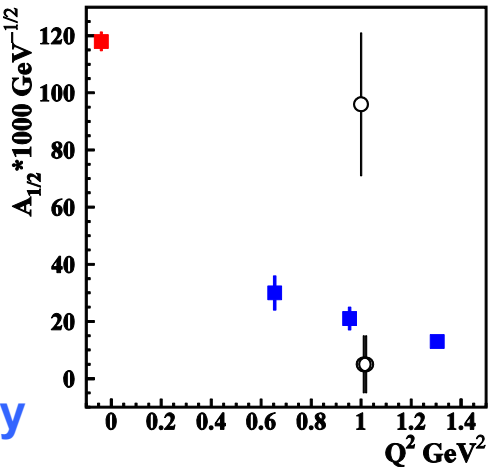


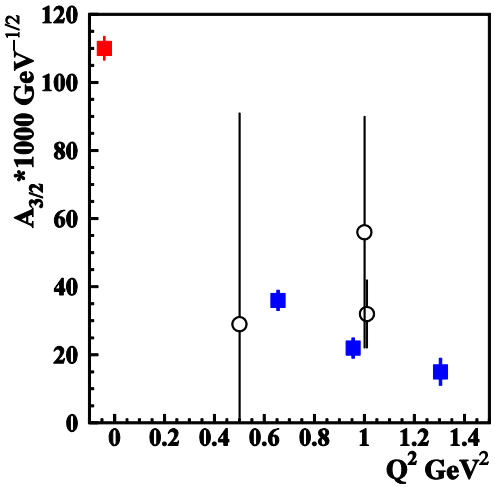
First results on correlated 2D (inv. mass & angle) cross sections offer new capabilities for the studies of reaction mechanisms

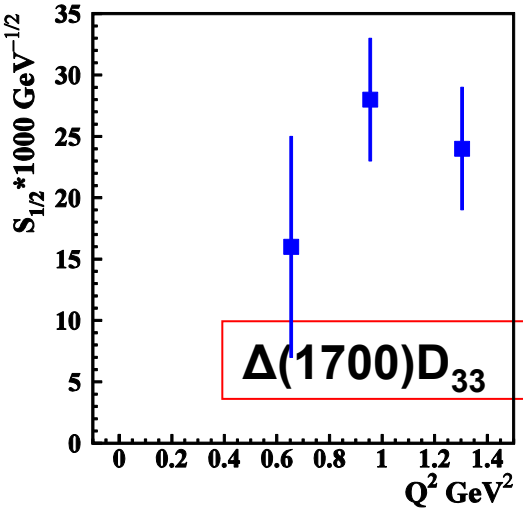
Direct experimental evidences for t-channel amplitudes in $\pi^-\,\Delta^{++}$, π^+ D13(1520), ρp isobar channels incorporated into the JM model

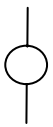
High lying resonance electrocouplings from Nππ CLAS data analysis

Nππ CLAS preliminary



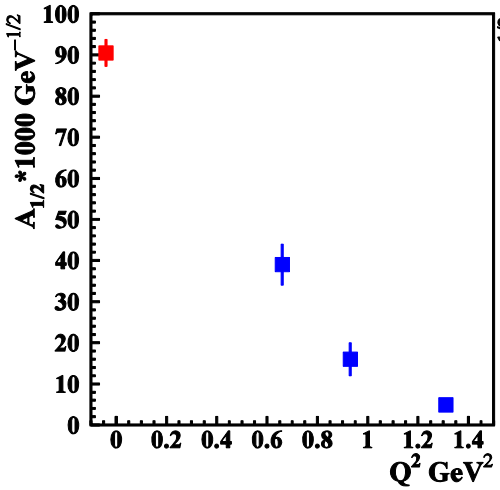


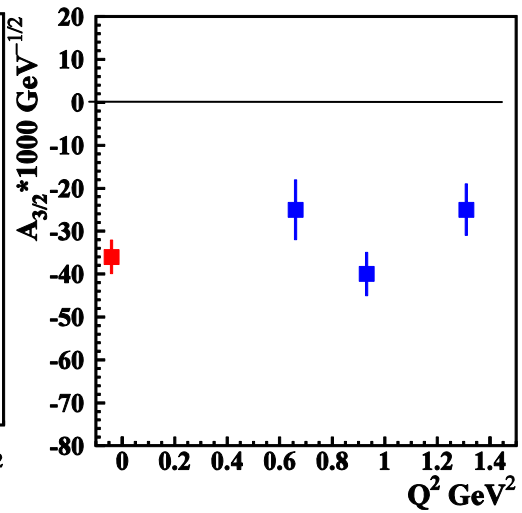


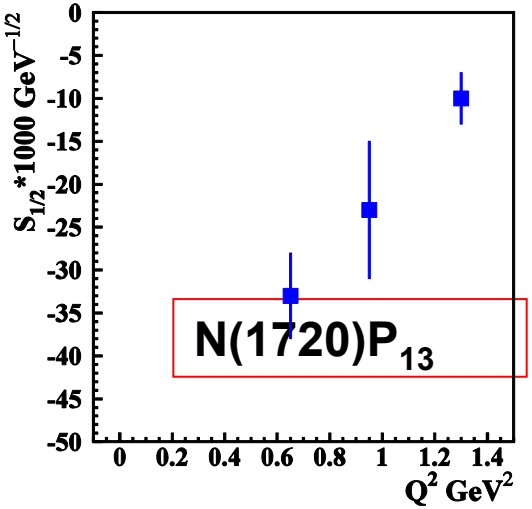


Nπ world

Nπ CLAS Q^2=0

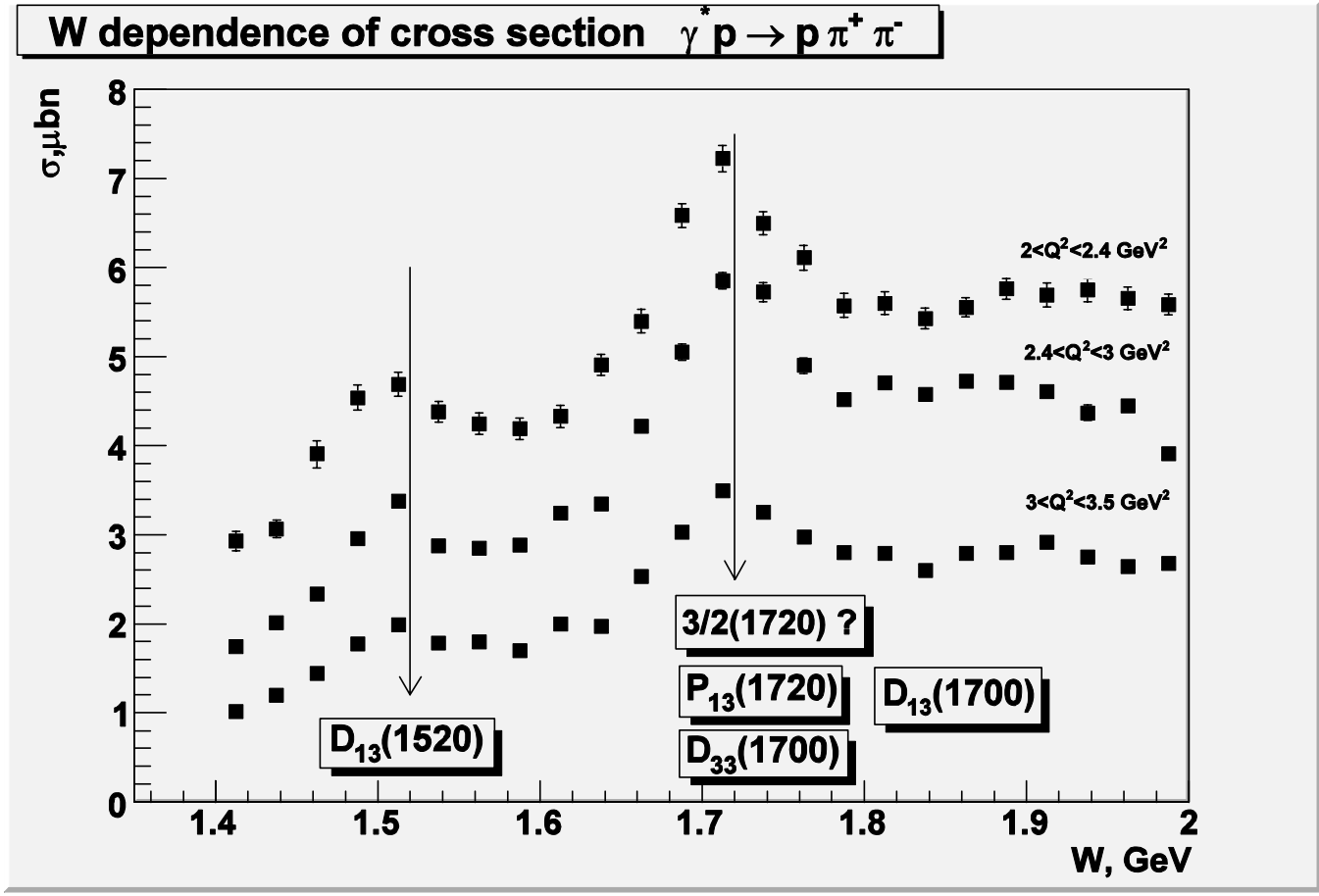






Nππ electroproduction at high Q^2. E.L.Isupov

First data on electrocouplings of almost all N*'s at $2.0<Q^2<5.0$ GeV^2 from Nππ electro production off protons



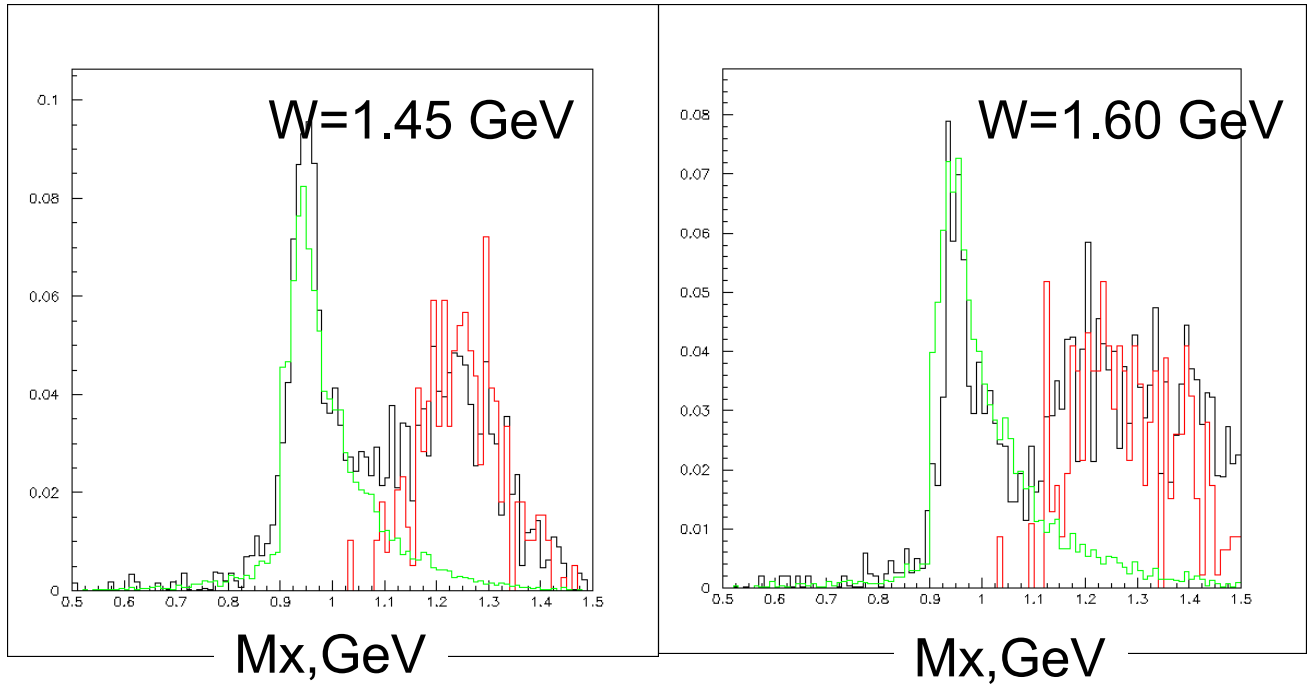
- Evidence for substantial resonance contributions.
- Srtructure at 1.7 GeV becomes more pronounced at high Q^2.

Nπ electroproduction off deuterons from e1e data. N.V.Shvedunov

ep(n)->e'π^+n(n)
informatrion on
binding effects

en(p)->e'π^-p(p)
π^-p cross sections
off free neutrons

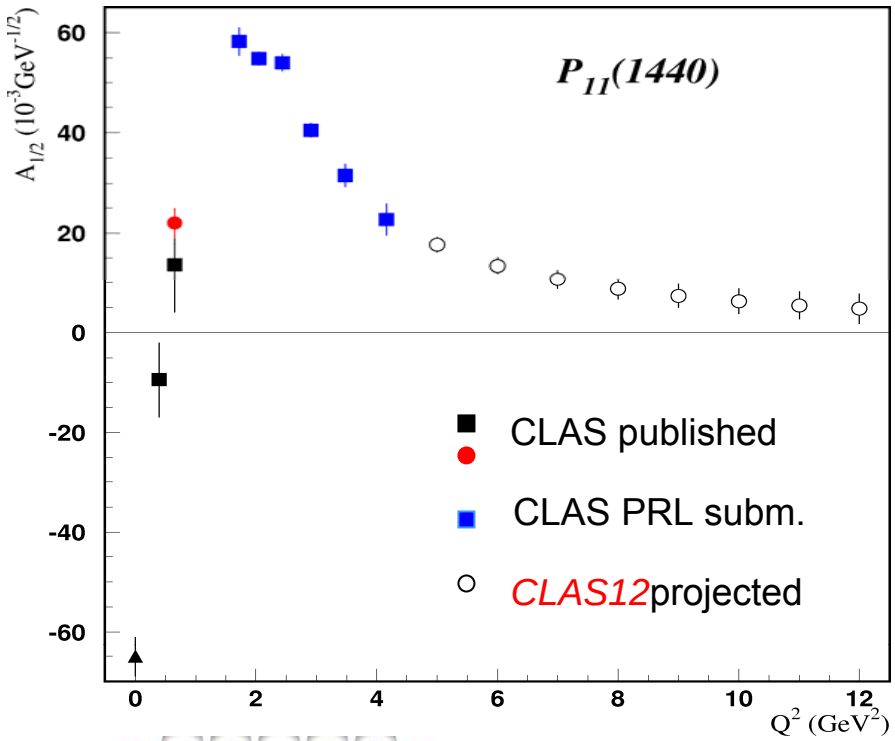
ep(n)->e'π^+X(n)
Q^2=0.4 GeV^2

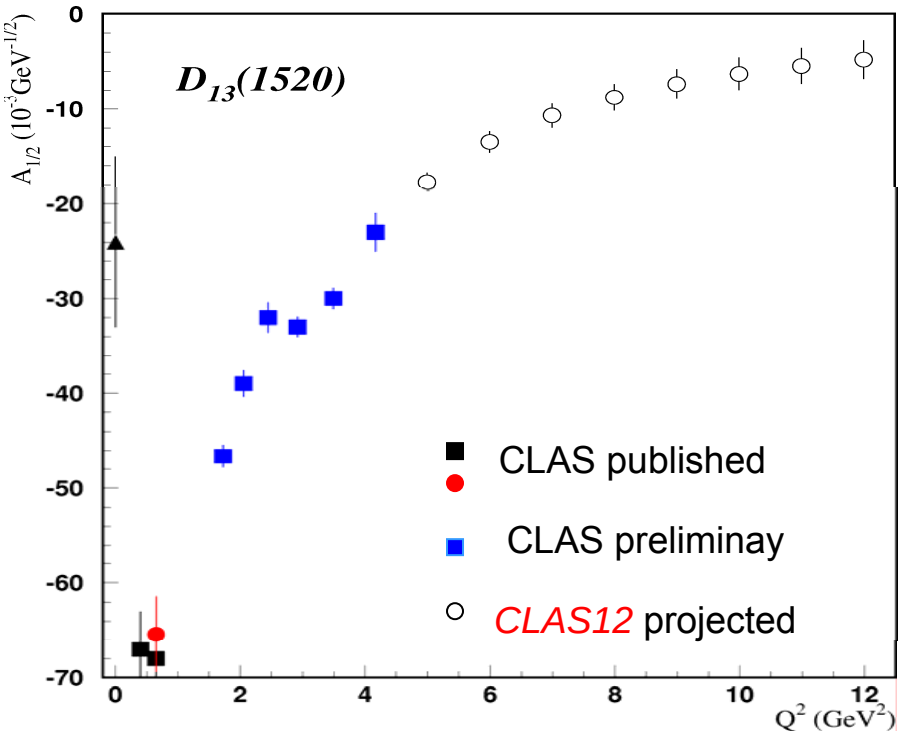


The ultimate goal: evaluation of N-N* electrocouplings off neutrons

CLAS12 Projections for N* Transitions

For the foreseeable future, CLAS12 will be the only facility worldwide, which will be able to access the N* electrocouplings in the Q^2 regime of 5 GeV^2 to 10 GeV^2, where the quark degrees of freedom are expected to dominate.





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

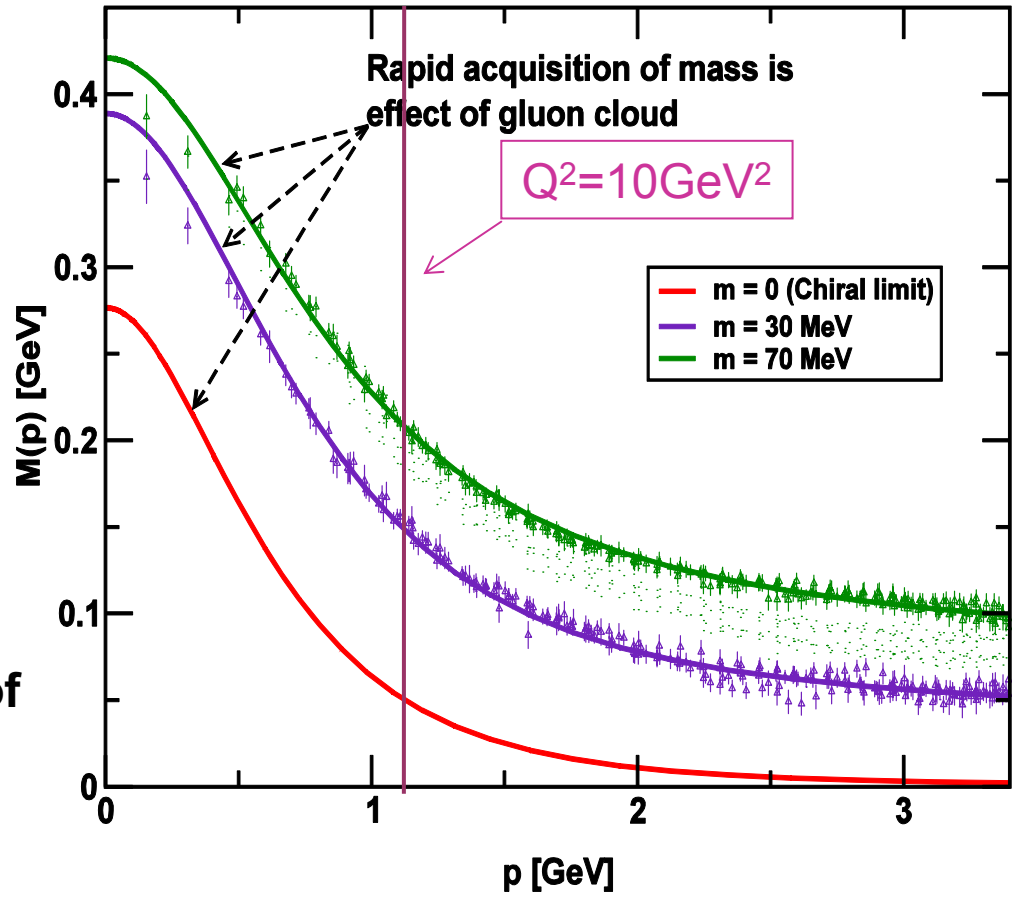
http://www.physics.sc.edu/~gothe/research/pub/nstar12-12-08.pdf.

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]

Spokesperson
Contact Person*

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.**



DSE: lines and LQCD: triangles

Q^2 = 10 GeV^2 = (p times number of quarks)^2= 10 GeV^2→ p = 1.05 GeV

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/

Parallel sessions #9,13 of GHP09 Workshop

Theory Support Group

V.M. Braun[8], I. Cloët[9], R. Edwards[5], M.M. Giannini[4,7], B. Julia-Diaz[2], H. Kamano[2], T.-S.H. Lee[1,2], A. Lenz[8], H.W. Lin[5], A. Matsuyama[2], M.V. Polyakov[6], C.D. Roberts[1], E. Santopinto[4,7], T. Sato[2], G. Schierholz[8], N. Suzuki[2], Q. Zhao[3], and B.-S. Zou[3]

JLab PAC 34, January 26-30, 2009

Argonne National Laboratory (IL,USA)[1],
Excited Baryon Analysis Center (VA,USA)[2],
Institute of High Energy Physics (China)[3],
Istituto Nazionale di Fisica Nucleare (Italy)[4],
Jefferson Lab (VA, USA)[5],
Ruhr University of Bochum (Germany)[6],
University of Genova (Italy)[7],
University of Regensburg (Germany)[8],
and University of Washington (WA, USA)[9]

Open invitation.

List is open to any and all who wish to participate!

Outlook

A wide international collaboration is needed for

- **theoretical interpretation on the N* electrocouplings (see http://www.jlab.org/~mokeev/white_paper)**
- **development of reaction models that will be capable to take into account the contributions from the quark/parton degrees of freedom at high Q^2.**
- **development of the methods for experimental data analysis**

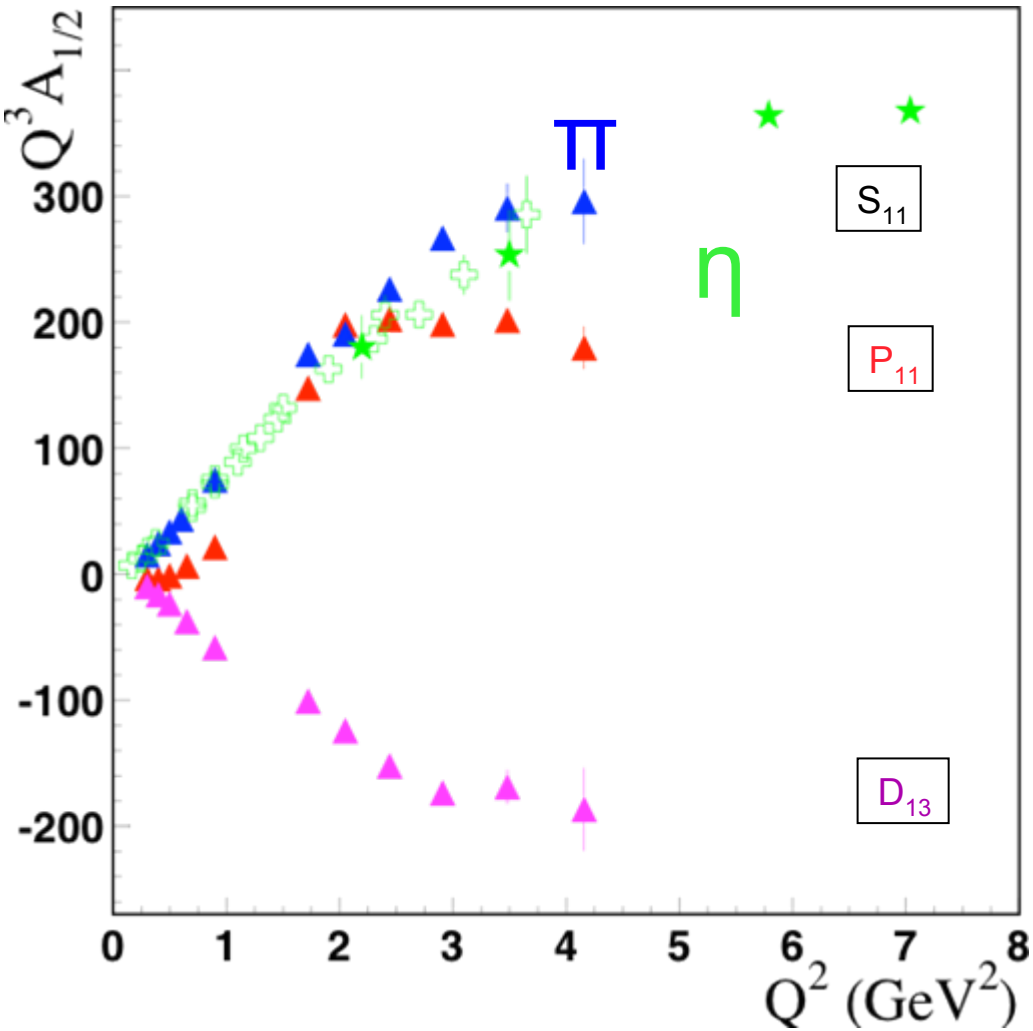
Everybody willing to contribute please contact Ralf Gothe gothe@sc.edu or Victor Mokeev mokeev@jlab.org

Back-up

Resonance scaling behavior?

Resonance transition amplitudes should scale asymptotically as:

$Q^3A_{1/2}$



Conclusions

- Phenomenological approaches have been developed with the goal of determining N* electrocouplings from combined fits of measured observables in $N\pi$ & $N\pi\pi$ electroproduction data.

- A good description of the CLAS data on $N\pi$ electroproduction and differential cross sections in $\pi^+\pi^-p$ channel has been achieved, affording us to access the resonant parts of amplitudes, which are directly related to N* electrocouplings.

- The $P_{11}(1440)$ and $D_{13}(1520)$ electrocouplings have been determined for the first time from both the $N\pi$ & $N\pi\pi$ datasets.

- The consistent results extracted from these two channels strongly indicate a reliable electrocoupling measurement.

- Preliminary results on electrocouplings of high lying $D_{33}(1700)$, $P_{13}(1720)$ resonances have been obtained from analysis of the $N\pi\pi$ CLAS data.

- Comparison of the data on N* electrocouplings with quark model expectations in coordination with EBAC evaluations for MB cloud show that for $Q^2<1.0$ GeV^2 both the MB cloud and quark core play an important role in the N* structure.

- Contribution from the MB cloud decreases with Q^2, but can be still sizable at $Q^2<5.0$ GeV^2, while at $Q^2>5.0$ GeV^2 quark degrees of freedom are expected to dominate.

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

3/2

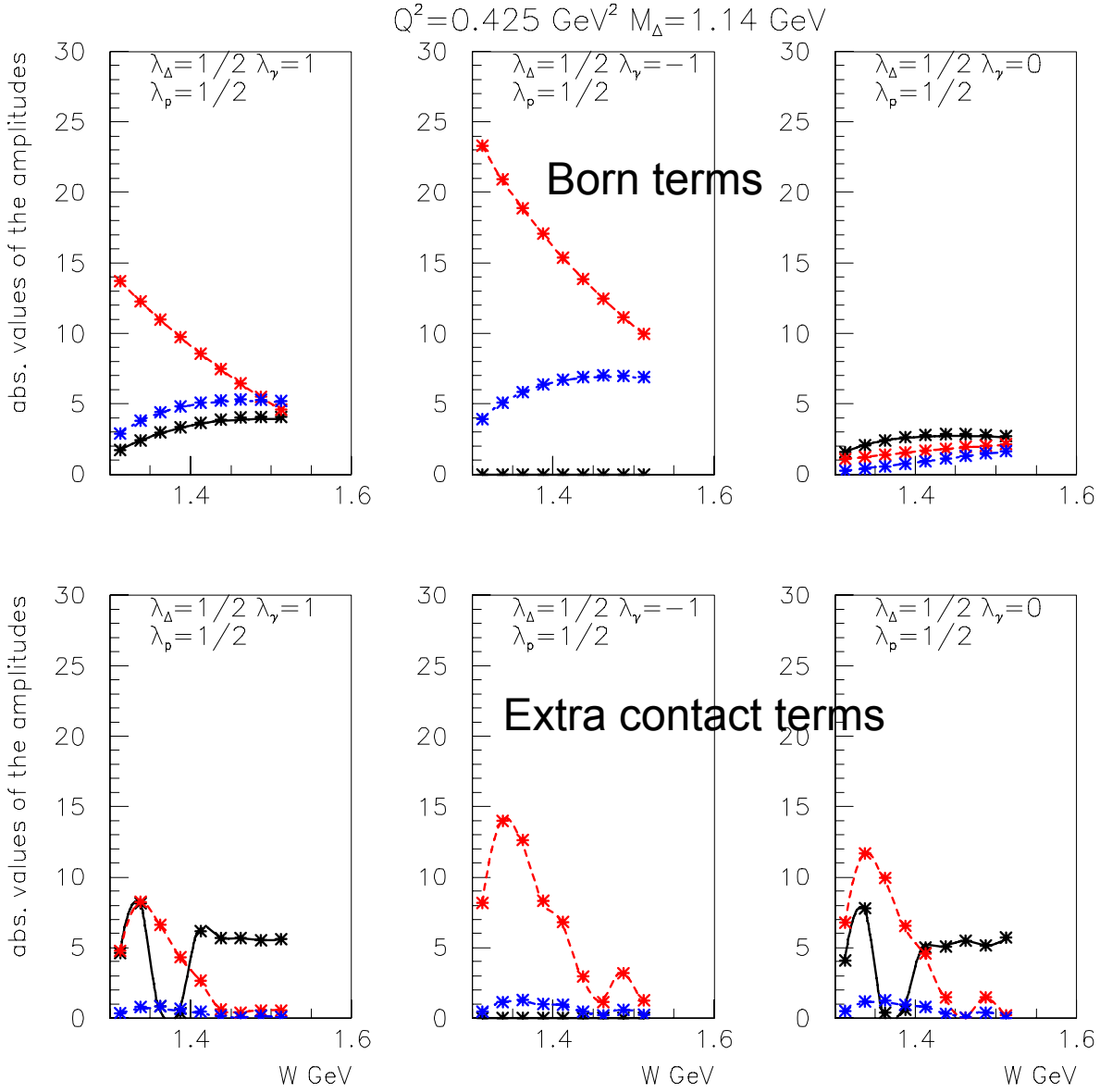
5/2

$$\left\langle \lambda_f \left| T^J \right| \lambda_\gamma \lambda_p \right\rangle =$$

$$\int \frac{2J+1}{2} \left\langle \lambda_f \left| T \right| \lambda_\gamma \lambda_p \right\rangle \bullet$$

$$d^J_{\mu\nu}(\theta_f) \sin\theta_f d\theta_f$$

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



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

Ground p state

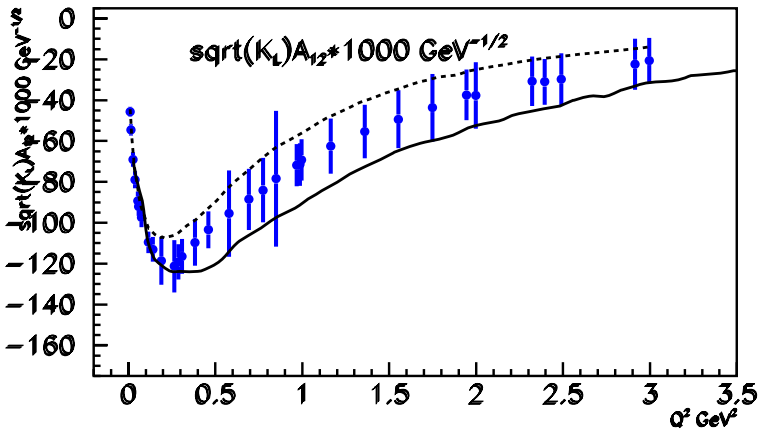
P11(1440)

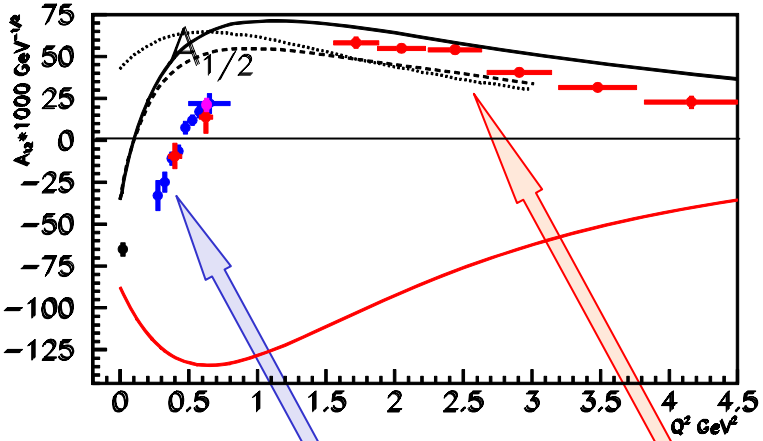
S.Capstick light cone (LC) model

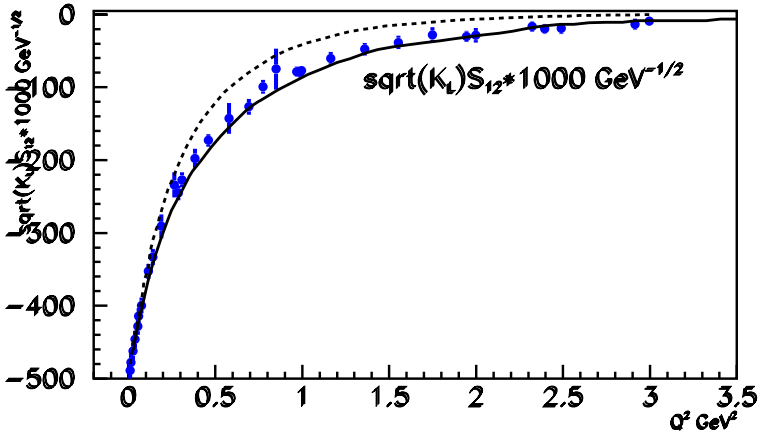
B.Metsch Bethe-Salpeter model

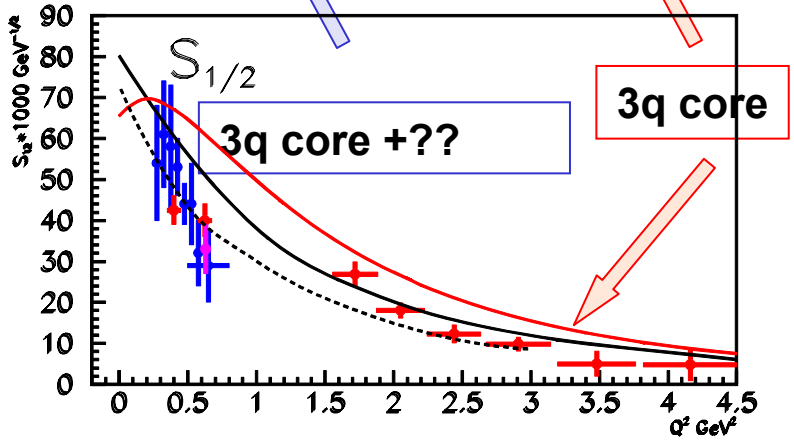
I.Aznauryan LC model

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.

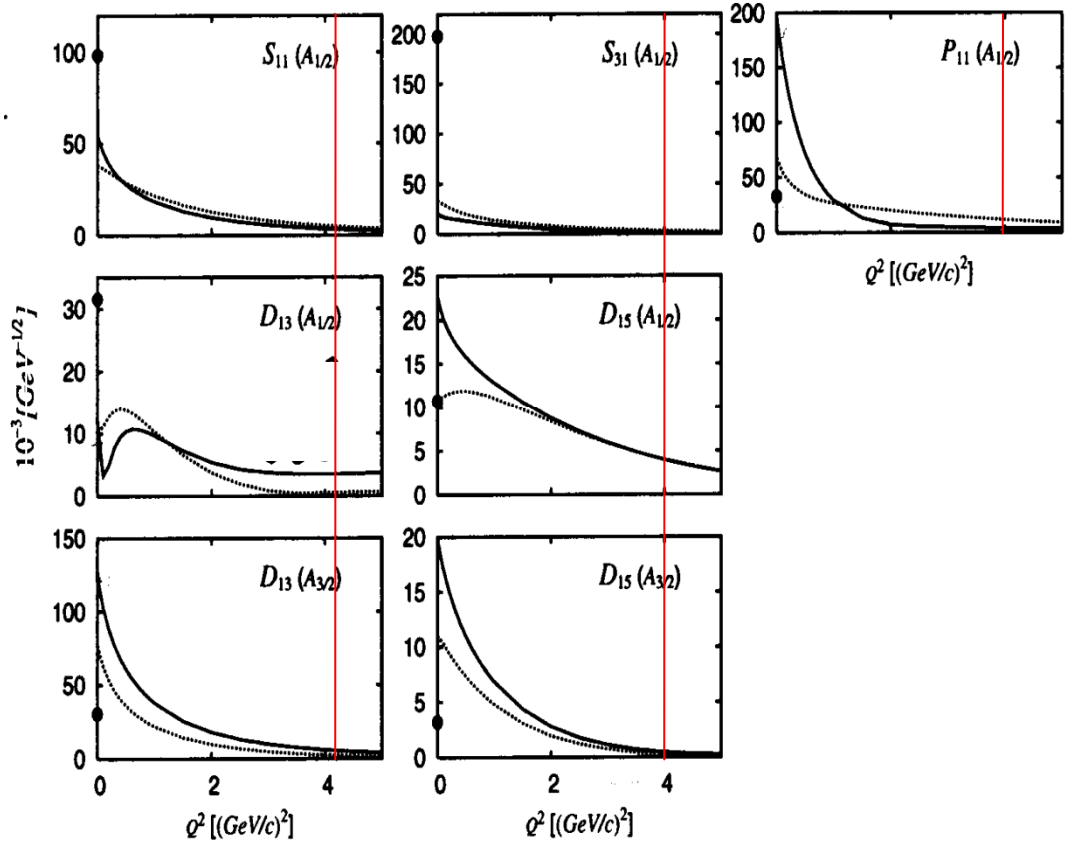
New regime in N* excitation at high Q^2

- **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**

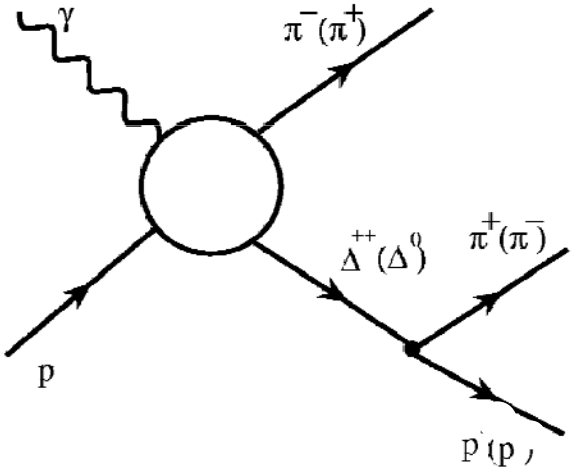
EBAC calculations for meson-baryon cloud of low lying N*'s.

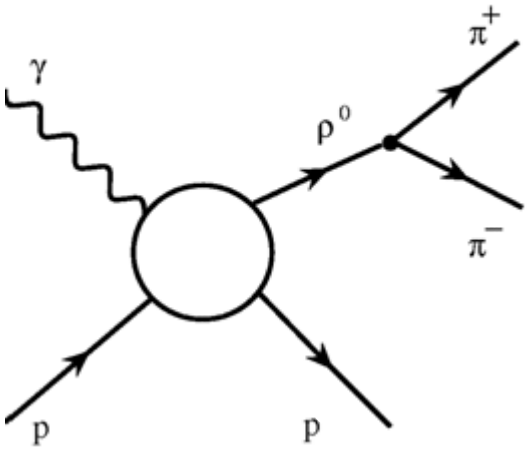


B.Julia-Diaz, T-S.H.Lee, et.al, Phys. Rev. C77, 045205 (2008).

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

3-body processes:





Isobar channels included:

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

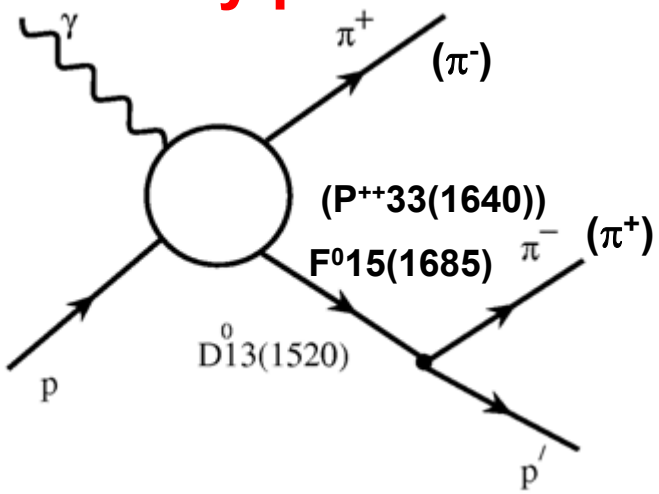
- **All well established N*s with $\pi\Delta$ decays and $3/2^+(1720)$ candidate, seen in CLAS 2π data.**
- **Reggeized Born terms with effective FSI & ISI treatment .**
- **Extra $\pi\Delta$ contact term.**

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.**

continued

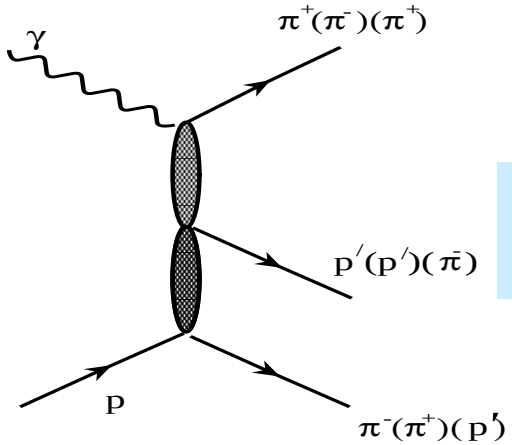
3-body processes:



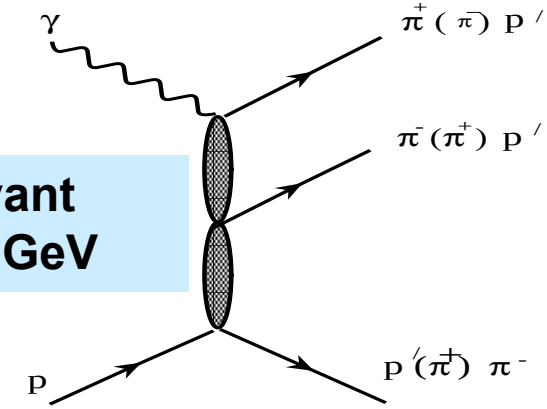
Isobar channels included:

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

Direct 2π production

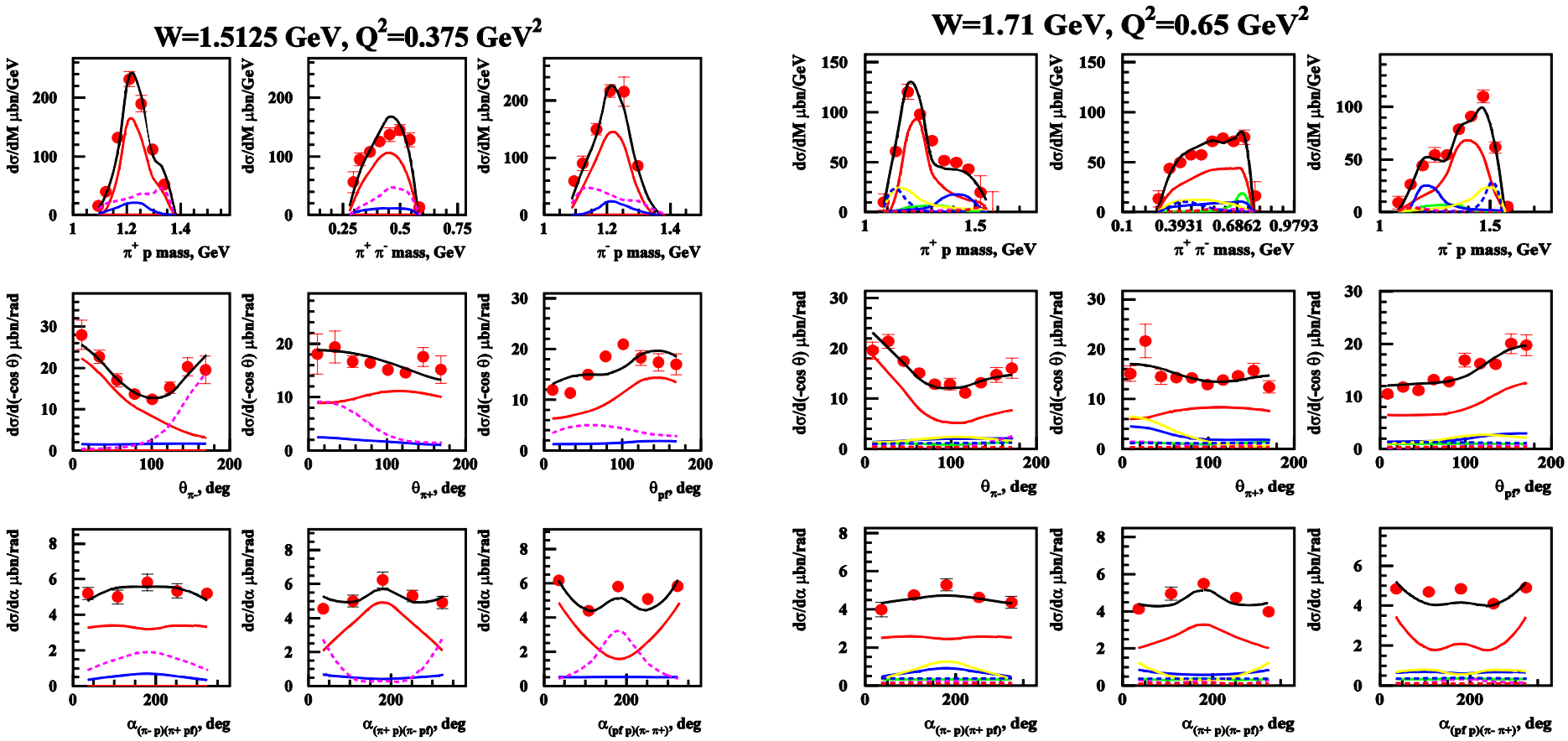


Most relevant at W<1.65 GeV



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

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



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

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