N* studies in double charged pion photo- and electroproduction.

Victor Mokeev

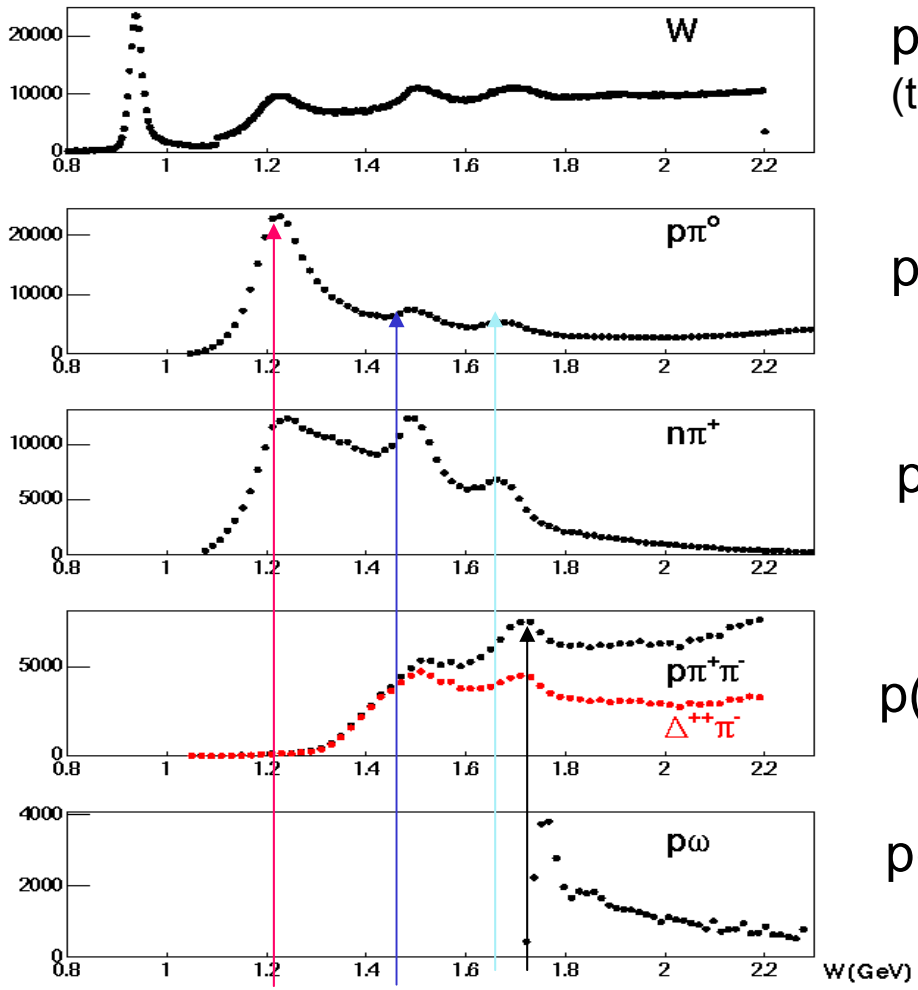
Outline:

- Significance of 2π exclusive channel in N* physics and need for dynamical models
- JLAB-MSU model (2003'-version)
- Evidences for new mechanisms from analysis of recent CLAS data on 2π photo- and electroproduction
- Comprehensive test of the recent JLAB-MSU model in combined analysis of CLAS data on 1π and 2π electro-production
- N* photocouplings from analysis of CLAS 2π data within the framework of the recent JLAB-MSU model
- Conclusion and outlook

N* in CLAS data.

Single pion production is sensitive to low lying N* 's (<1.65 GeV masses), while double pion channel has contributions from most N* states heavier than 1.4 GeV

$Q^2<4.0 GeV^2$



p(e,e')X (trigger)

$p(e,e'p)\pi^0$

$p(e,e'\pi^+)n$

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

$p(e,e'p\pi^+)X$

2 π exclusive channel in N* studies.

The 2π exclusive channel is sensitive both to low and high lying N*' and allows us to determine the photocouplings for most N* with masses below 2.0 GeV, in particular, for the states which mostly decay to the 2π: S31(1620), D13(1700), D33(1700), P13(1720), F35(1905), F37(1950).

Combined analysis of 1π and 2π exclusive channels, accounting for major part of the total cross-sections in N* excitation region, enables us to extract reliable data on N* photocouplings, minimizing uncertainties of phenomenological resonant/background separation and providing sensitive test for credibility of 1π and 2π dynamical models.

Double pion production by photons off protons offers a promising way to search for unobserved nucleon excitations, the so-called "missing" baryon states.

Analysis of 2π production.

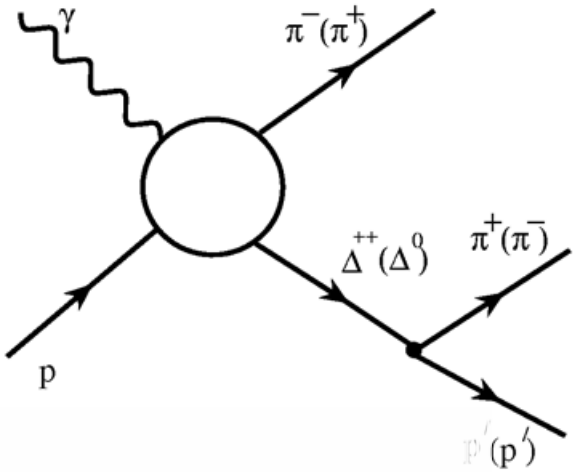
- **Complicated background, determined by competition of many mechanisms. Contributions from many partial waves (several tens) make model-independent partial wave analysis difficult. PWA application in 2π channel is currently restricted by real photon data only.**

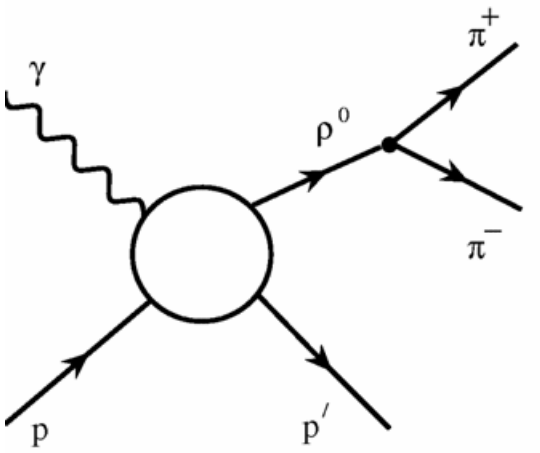
- **Comparable N*/background contributions for most partial waves. In such condition a model independent isolation of N* contribution becomes impossible.**

- **Reliable evaluation of N* photocouplings requires development of dynamical models for 2π photo- and electro- production, which relate N* photocouplings to measured observables.**

JLAB-MSU model for 2-π electroproduction (2003'-version).

3-body processes





Quasi-2-body mechanisms included

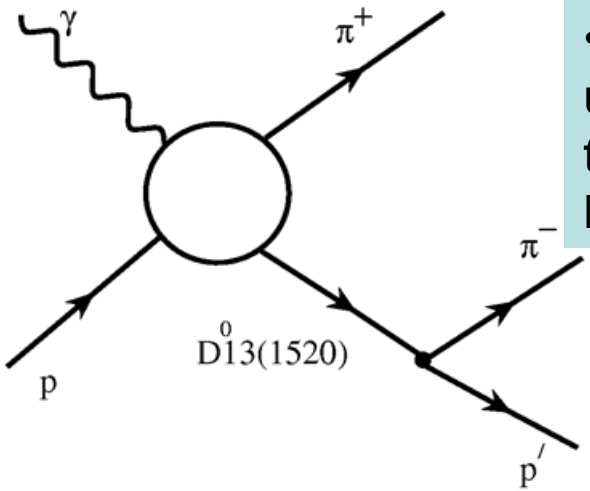
- All well established N* with πΔ decays +P33(1600)&P11(1710)&P13(1720) 3-star states
- Minimal set of Reggetized gauge invariant Born terms
- Effective treatment of couplings with other open channels

- All well established N* with ρp decays +P11(1710)&P13(1720) 3-star states.
- Diffractive ansatz for non-resonant ρp production

JLAB-MSU model (2003'-version).

3-body processes

Quasi-2-body mechanisms included



•Minimal set of Born terms similar to what was used for $\pi\Delta$ states, except an additional γ_5 matrix to account for the opposite parities of Δ and D13(1520)

Residual mechanisms, beyond shown on the plots, were parameterized either as 3-body phase space or through a set of partial waves with J<13/2. Both lead to a similar description.

Details of the 2003'-version of model may be found in:
M.Ripani et. al., Nucl. Phys., A672, 220 (2000);
V.Mokeev, et. al., Phys. of Atom. Nucl., 64, 1292 (2001);
V.D.Burkert, et.al., Phys. of Atom Nucl.,66, 2199 (2003);
V.D.Burkert, et. al., Phys. of Atom Nucl., 67, 1018 (2004);

Non-resonant mechanisms for ρp isobar channel. Modified diffractive ansatz.

$$T = A(Q^2)\exp(bt)$$ conv. diffr. ansatz

Modifications:

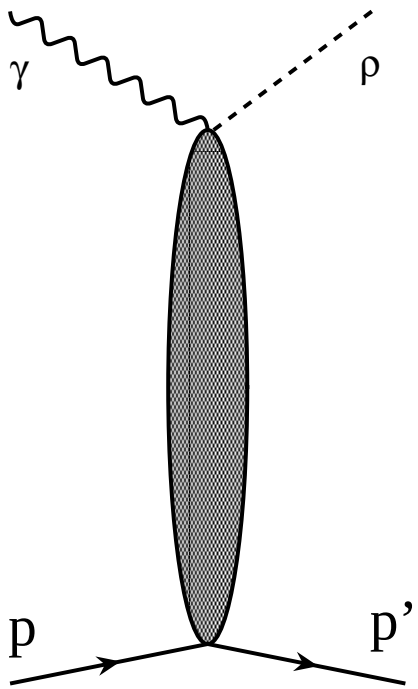
$$A(W,Q^2) = \frac{A_0(1-\exp(-(W-1.41)/D))}{1+Q^2/\lambda^2(W)}$$

insure proper amplitude behavior near threshold

$$\lambda(W) = \lambda_0(1-\exp(-(W-1.41)/D_\lambda))$$

accounts for ρ-line shrinkage at near/sub threshold areas in transition between photon and ρ meson

W in GeV; A_0=12, D=0.25 GeV,
λ_0= 0.77 GeV, D_λ=0.3 GeV



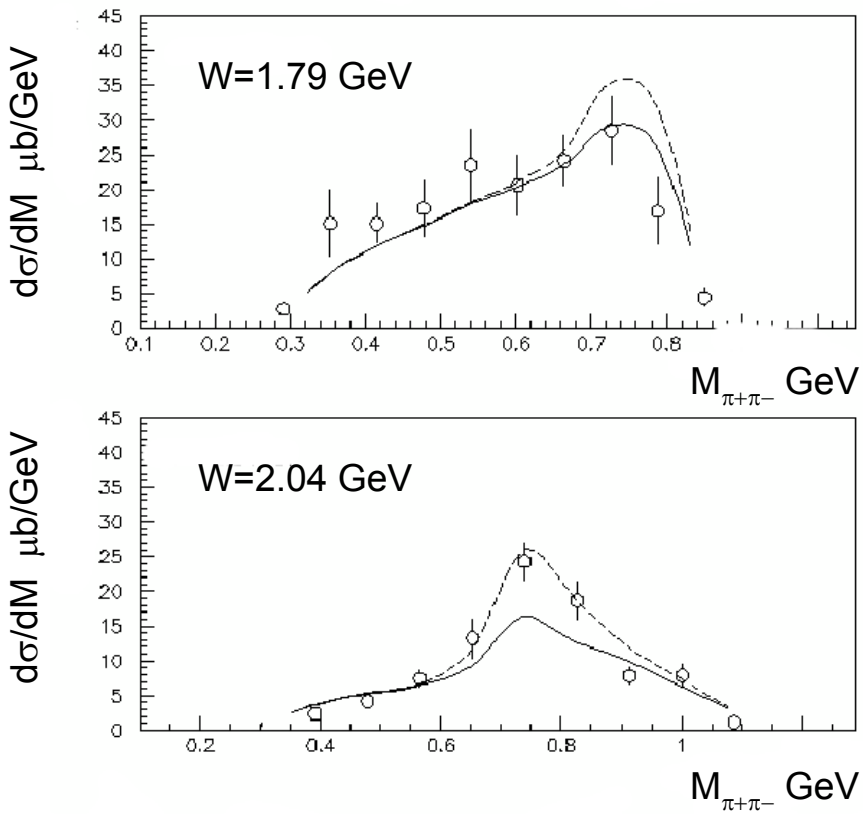
$$t = (p_p - p_{p'})^2$$

Description of the CLAS data on $\pi^+\pi^-$ inv. mass distributions with W-independent values of magnitude A_{diff} for non-resonant diffractive ρp production.

Q^2=1.30 GeV^2

——— A_{diff}=3.0

- - - A_{diff}=12.0

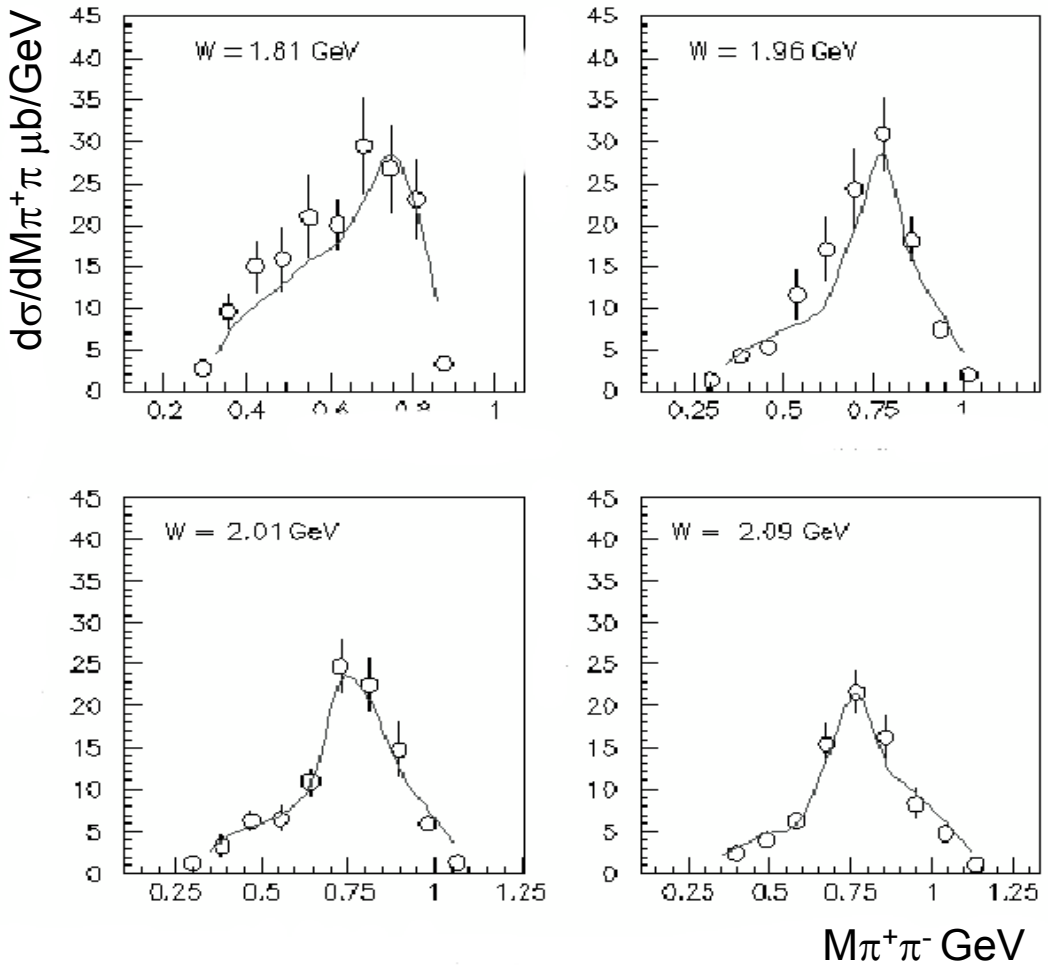


There is no way to describe the data in entire W-area, covered by measurements, with A_{diff} independent from W

Description of the CLAS data within the framework of modified diffractive ansatz.

N.Shvedunov, et. al.,submitted to Phys. of Atom. Nucl.,http://www.jlab.org/~gleb/shvedunov/shvedunov.pdf

$\pi^+\pi^-$ mass distributions at various W and Q^2=1.30 GeV^2

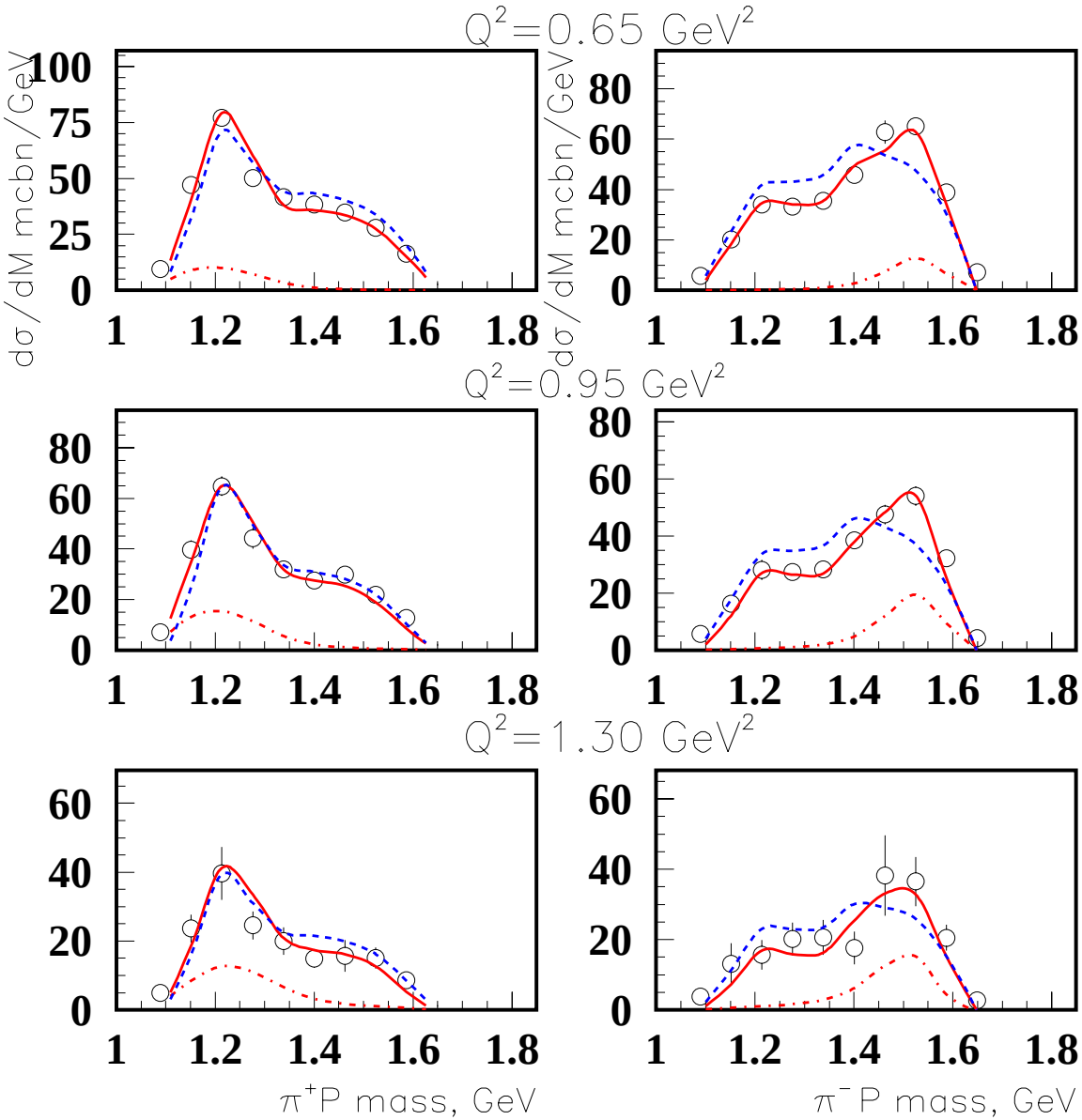


Description of π^+p, π^-p mass distributions at W=1.79 GeV.

$\gamma p \to \pi^+ D13(1520)$:

- – absorbed in 3b ph.space
- —— included
- – – contribution from sub-channel

Implementation of $\gamma p \to \pi^+ D13(1520)$ sub-channel allowed to reproduce CLAS data



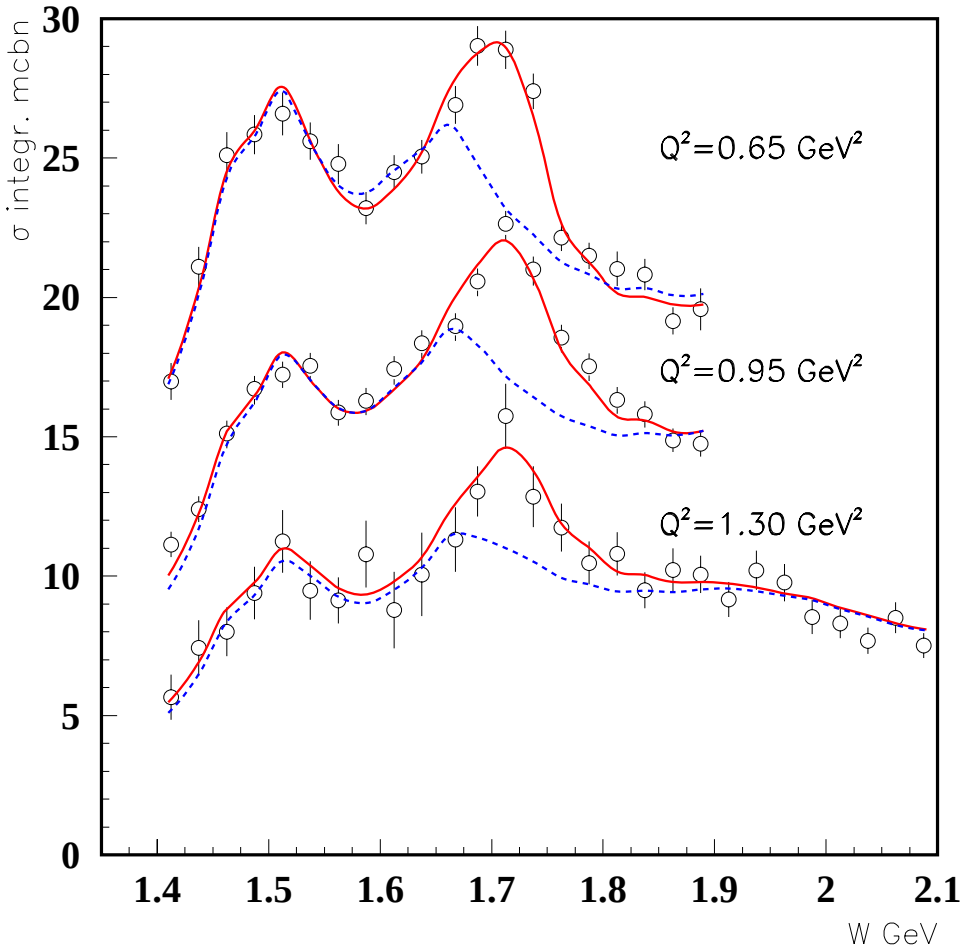
Electroproduction data fit. A possible new $3/2^+(1720)$ baryon state.

Contributions from conventional states only

Fit with new $3/2^+(1720)$ state

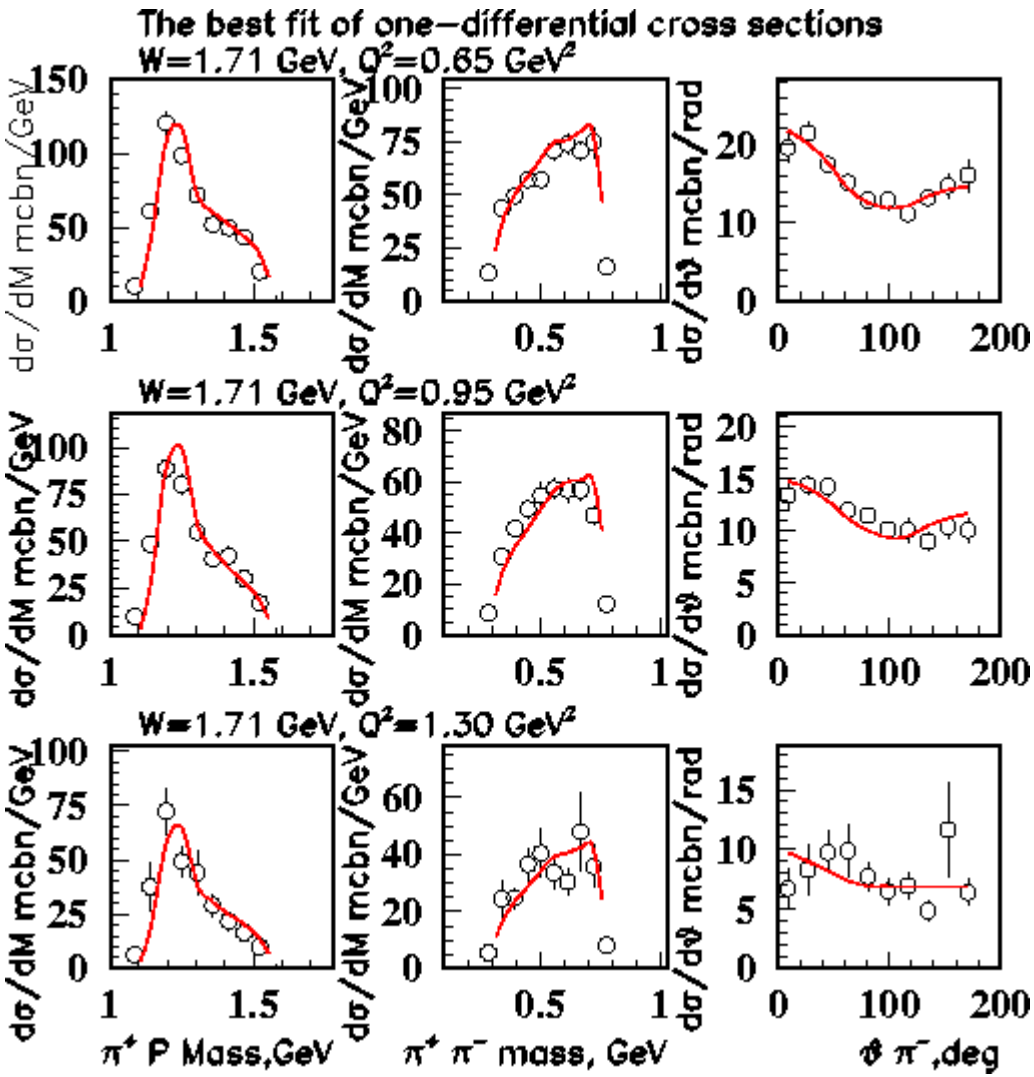
M.Ripani et. al.
Phys. Rev. Lett.91, 022002 (2003)

CLAS data fit



Difference between curves due to signal from possible $3/2^+(1720)$ state

Fitted differential 2π cross-sections.



Description of 1.7 GeV mass region.

Two alternative ways to describe CLAS data inside 1.7 GeV structure:

- Modification of hadronic couplings for P13(1720) PDG state with respect to established values
- Implementation of new baryon state with $J^{\pi} = 3/2^{+}$.

	M, MeV	Γ,MeV	$\Gamma_{\pi\Delta}/\Gamma$, %	$\Gamma_{\rho P}/\Gamma$, %
modified P13(1720)	1725±20	114±19	60±12	19±9
PDG P13(1720)	1650-1750	100-200	absent	70-85
"new state" $3/2^{+}$(1720)	1720±20	88±17	41±13	17±10

2π direct production mechanisms at the photon point.

..... JLAB-MSU model 2003-version, described on p.5-6

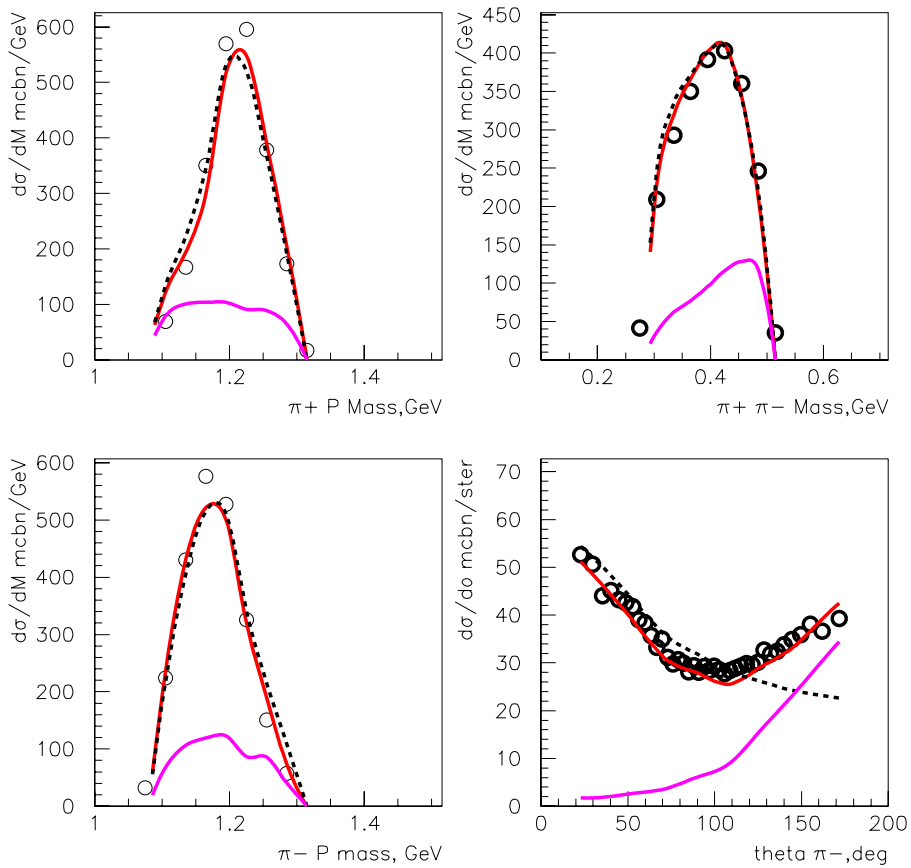
——— Improved JLAB-MSU model, see p. 8-27

——— 2π direct production

Preliminary real photon data from:

M.Bellis, et. al., (CLAS Collaboration) Proc of NSTAR2004 Workshop, March 24-27,2004, Grenoble, France, World Scientific 2005, ed. by J.-P.Bocquet, V.Kuznetsov, D.Rebreyend, 139

W=1.45 GeV



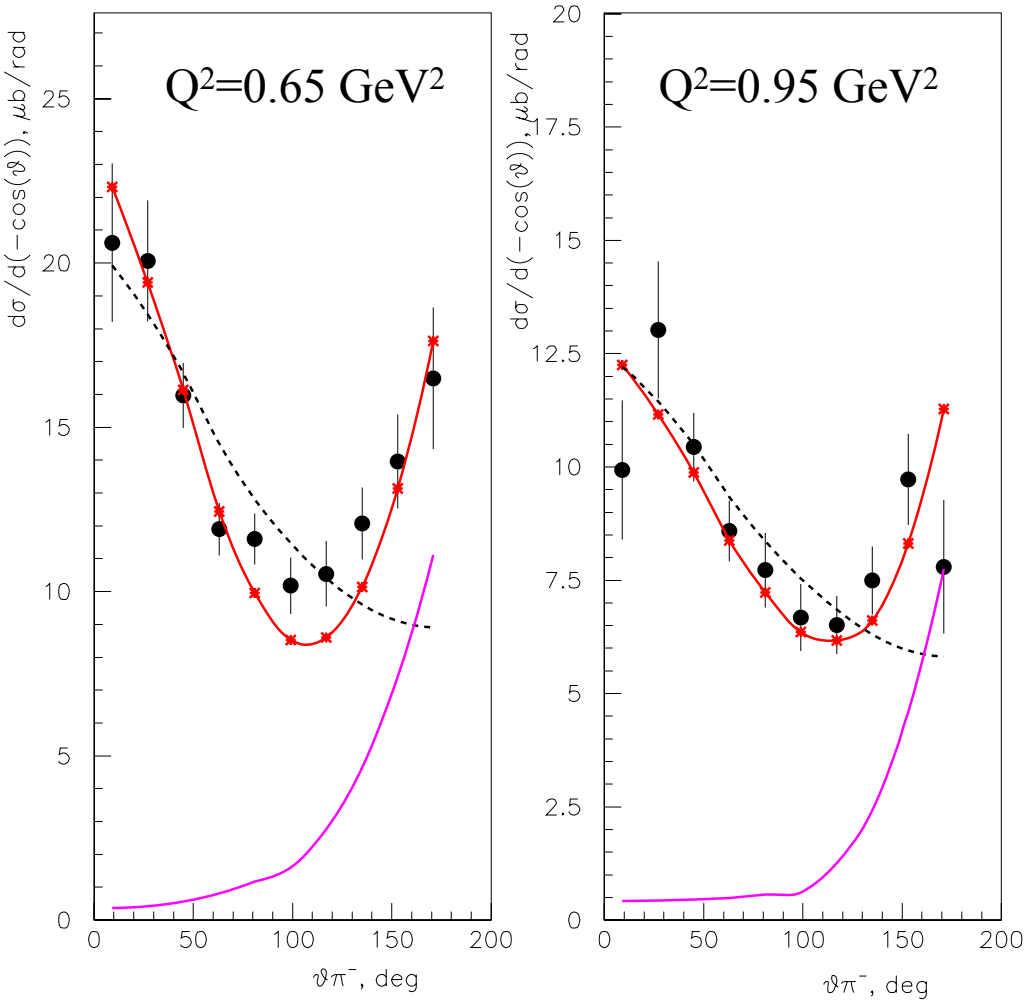
Manifestation of 2-π direct production at $Q^2>0$.

W=1.49 GeV

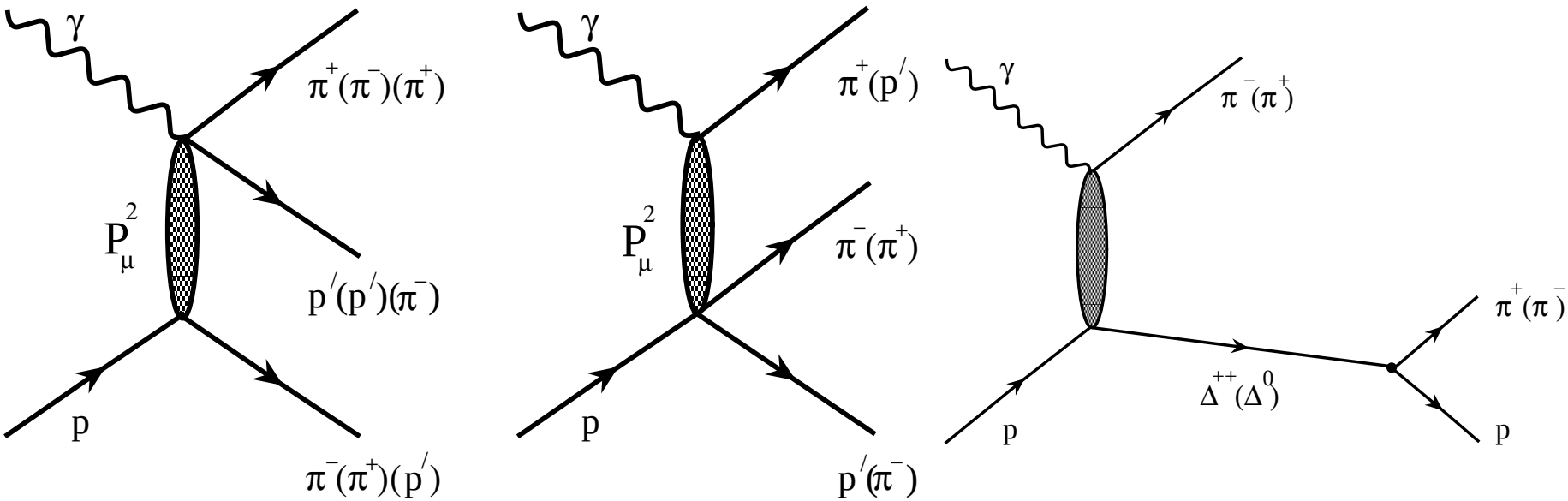
improved JLAB-MSU model

2003'-version

2π direct production



2π direct production mechanisms and an additional tensor term in πΔ channels needed to fit data.



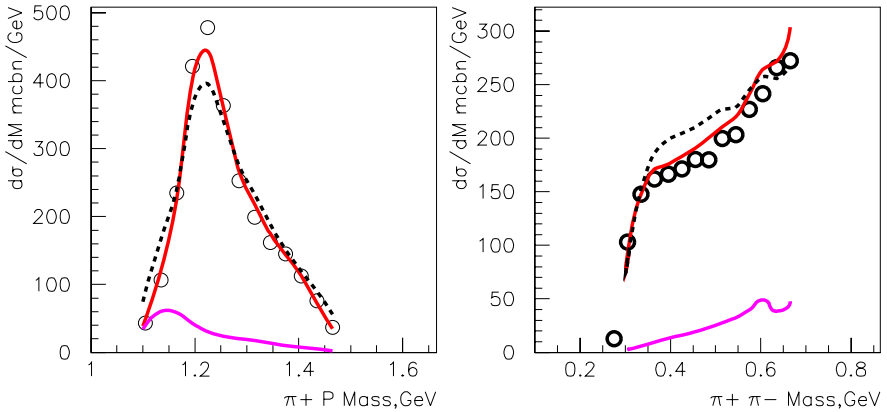
$$M_d = A(W,Q^2)\varepsilon_\mu^\gamma \overline{U}_{p'}\gamma_\mu U_p \frac{1}{W^4} e^{b(P_\mu^2 - P_{\mu\,\min}^2)}(P_1 P_2)$$

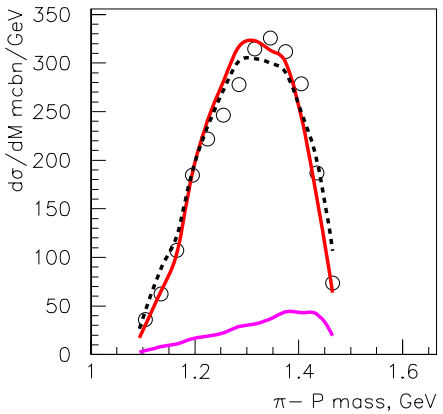
$$M_t = (A(W)\varepsilon_\mu^\gamma \overline{U}_{\Delta_\nu}\gamma^\mu U_p P_\pi^\nu + B(W)\varepsilon_\nu^\gamma \overline{U}_{\Delta_\nu}\gamma^\mu U_p (2P_\pi^\mu - P_\gamma^\mu))$$

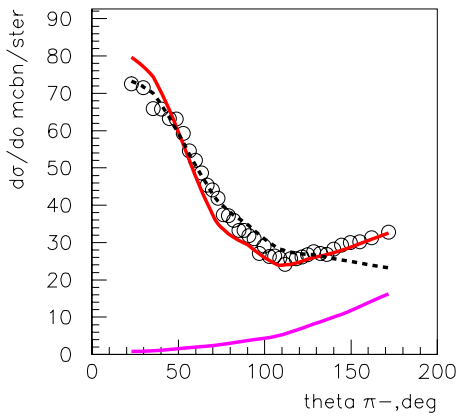
- $\dfrac{1}{t-\Lambda^2}$ $\quad \Lambda^2 = 1.64\ \mathrm{GeV}^2 \quad t = (P_\gamma - P_\pi)^2$

2π direct production and complementary tensor term at the photon point.

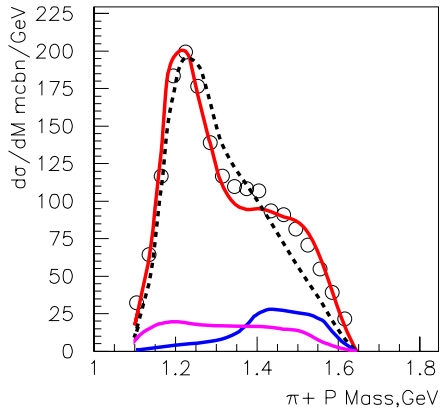
W=1.63 GeV

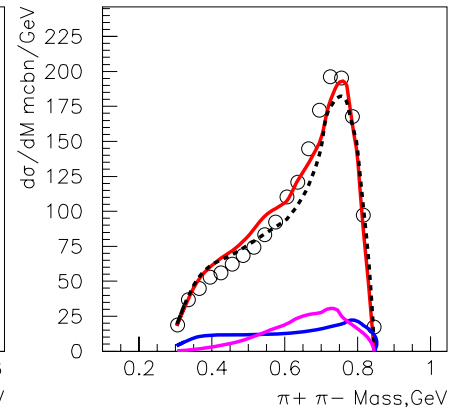


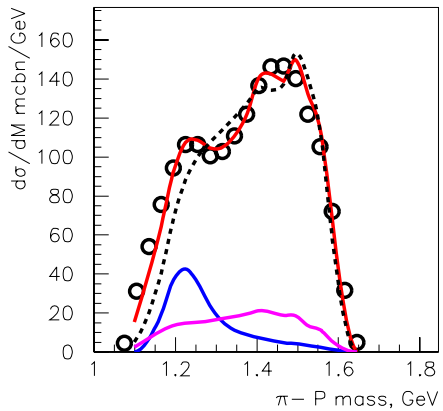


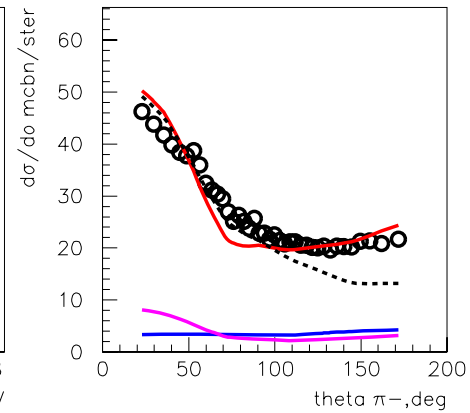


W=1.78 GeV









—— $\pi^+\Delta^0$ with complementary tensor term

Manifestation of complementary tensor term in $\pi\Delta$ channels at $Q^2>0$.

JLAB-MSU model:

improved

initial

Channels:

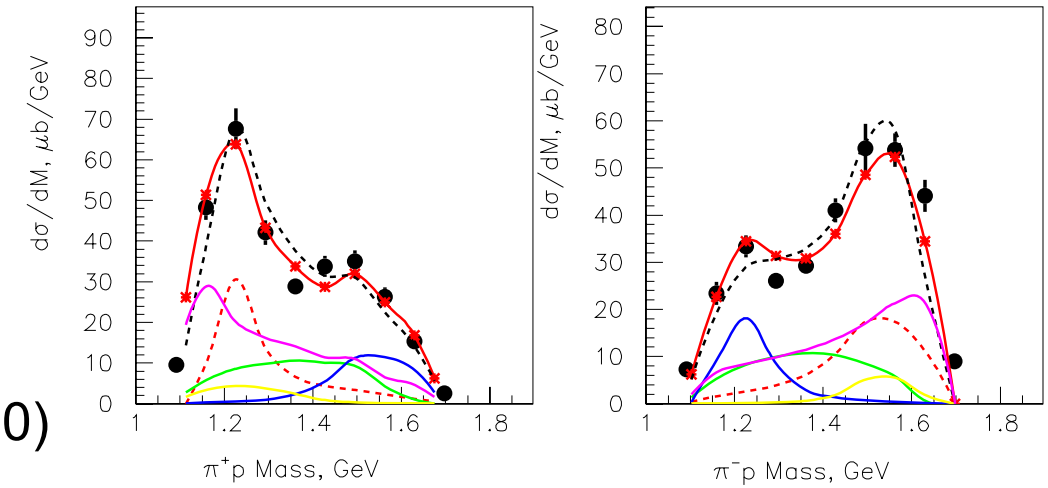
$\pi^-\Delta^{++}$ ρp

$\pi^+\Delta^0$ $\pi^+D_{13}(1520)$

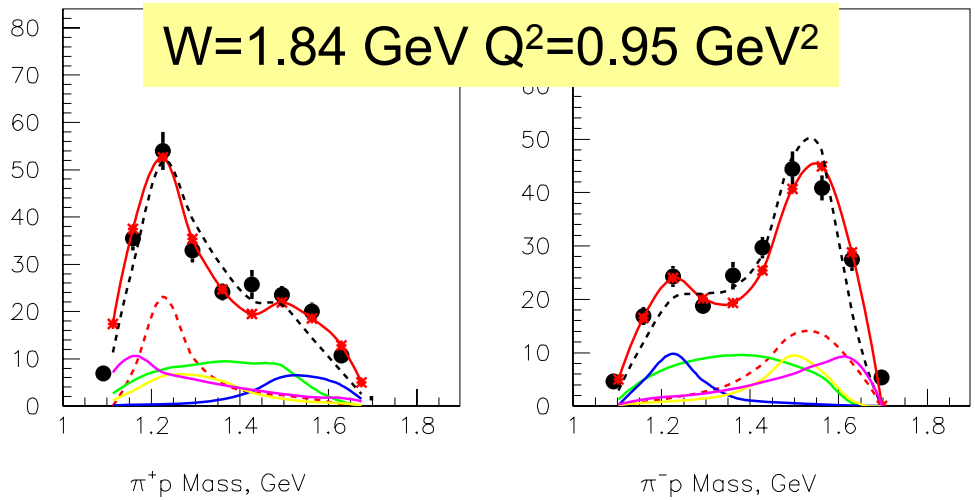
2π direct

Structure around Δ^0 peak in π^-p and high mass part in π^+p mass distributions are better described, implementing an additional tensor structure for $\pi\Delta$ chanels

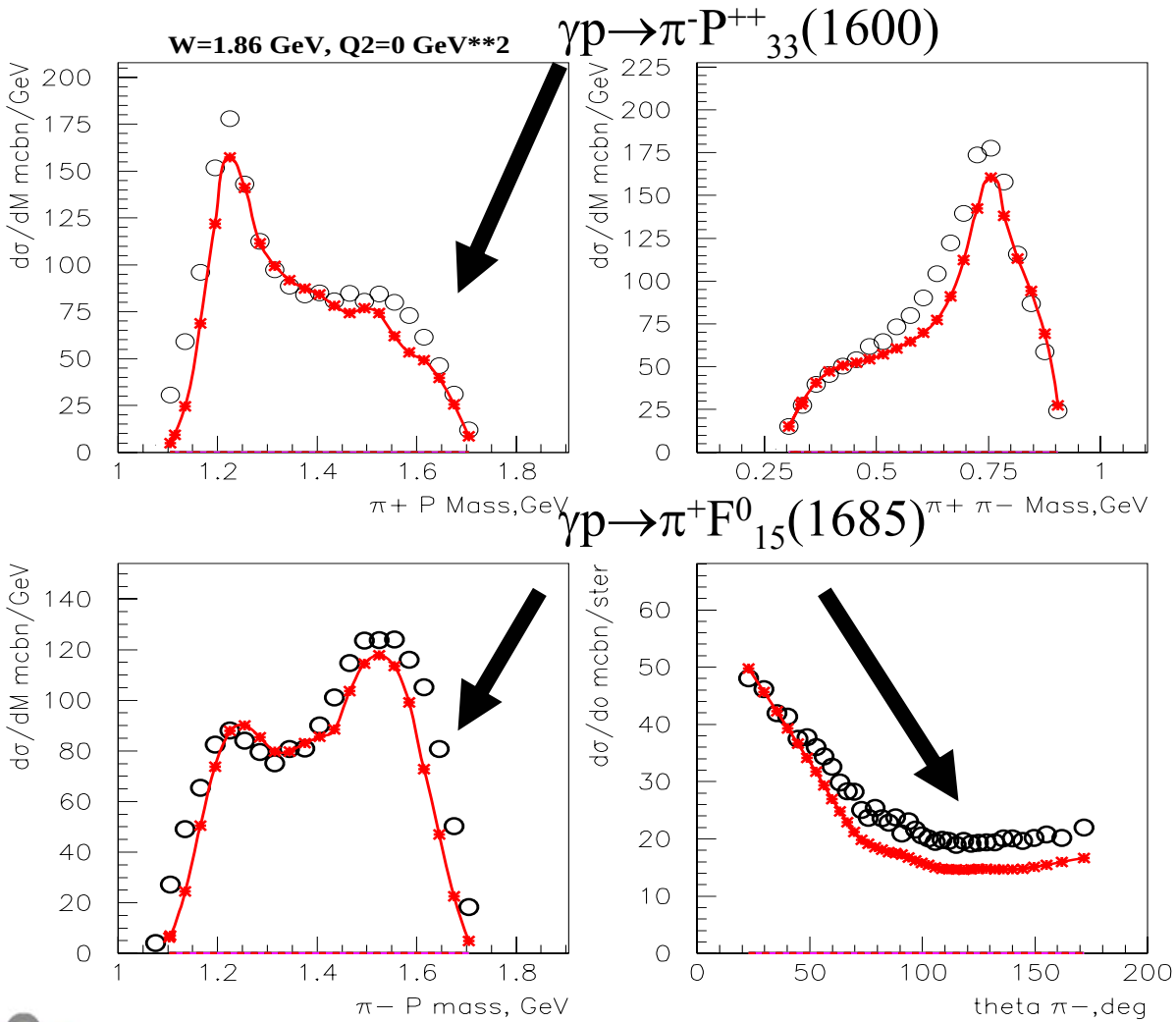
W=1.84 GeV Q^2=0.65 GeV^2



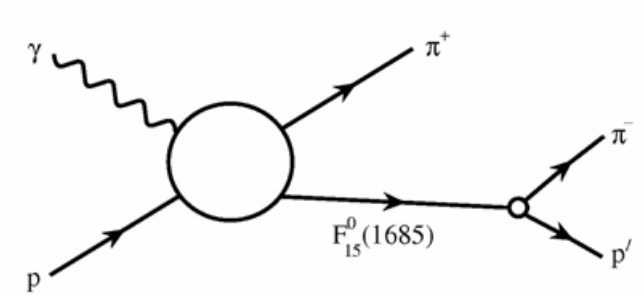
W=1.84 GeV Q^2=0.95 GeV^2



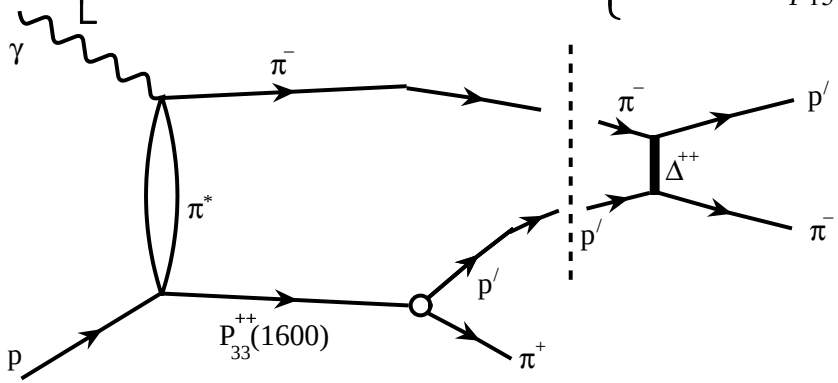
Evidence for $\gamma p \to \pi^+ F^0_{15}(1685)$ and $\gamma p \to \pi^- P^{++}_{33}(1600)$ channels.



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



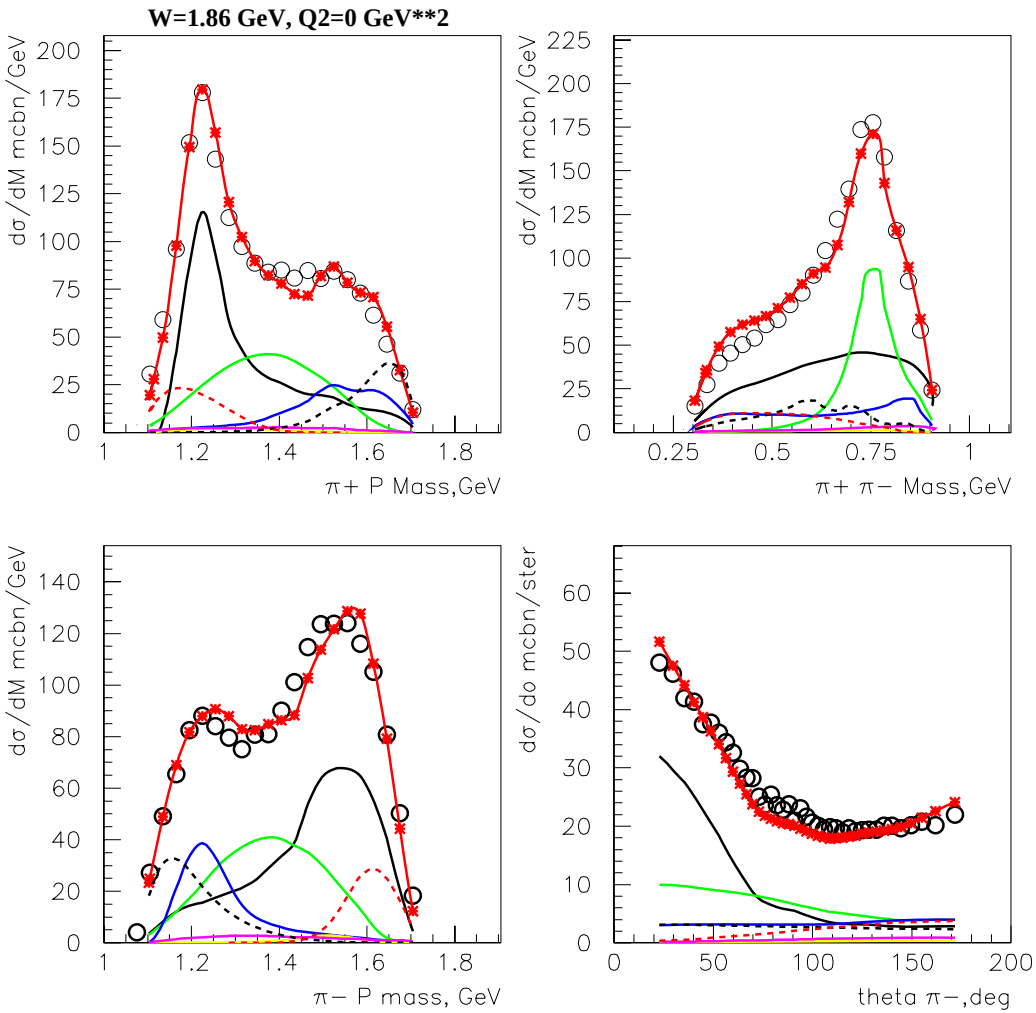
$$M = A(W,Q^2) \bullet \left[\varepsilon^{\gamma}_{\mu} \overline{U}_{p'} \gamma^{\mu} U_p (P_{F15} \bullet P_{\pi^+}) \bullet \exp\left\{ -\frac{(M_{\pi^- p} - M_{F15})^2}{\Gamma^2_{F15}} \right\} \right]$$



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

Fit of 2π photoproduction data at high W after implementation of new isobar channels.

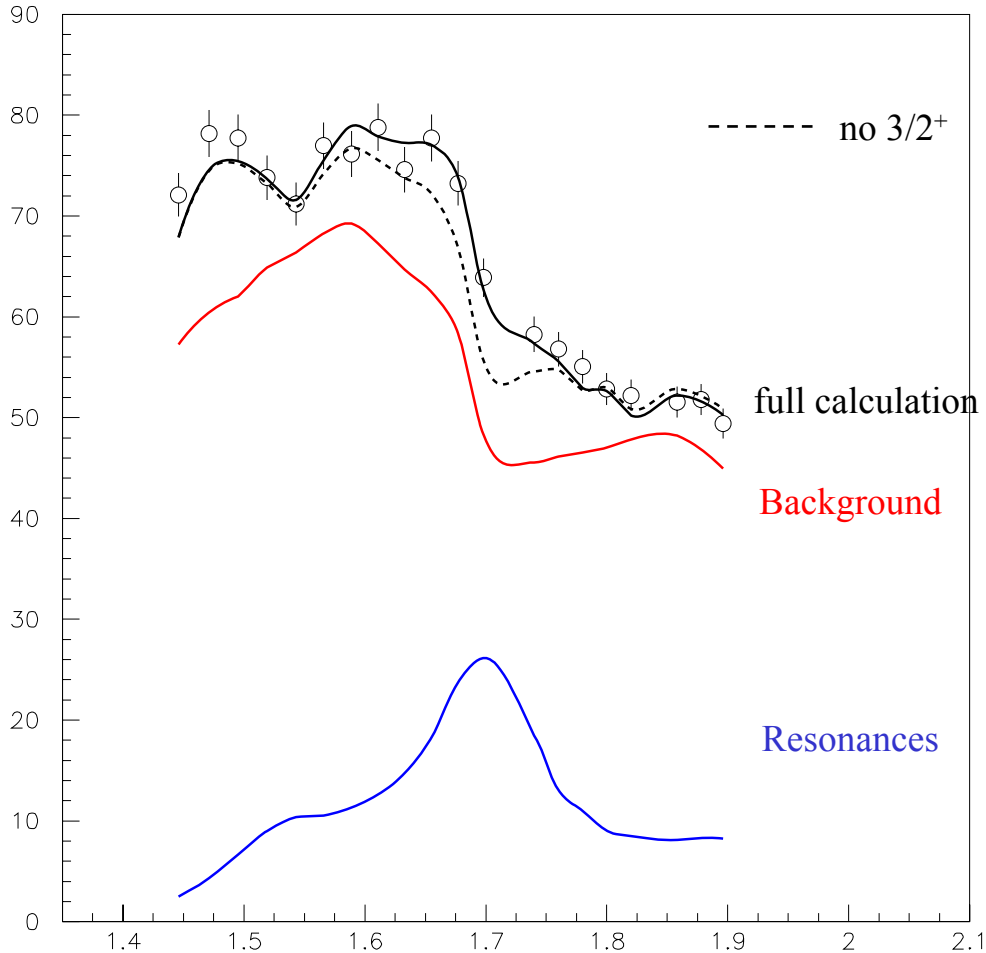
- Full calculations
- $\gamma p \rightarrow \pi^- \Delta^{++}$
- $\gamma p \rightarrow \pi^+ \Delta^0$
- $\gamma p \rightarrow \rho p$
- $\gamma p \rightarrow \pi^- P^{++}_{33}(1600)$
- $\gamma p \rightarrow \pi^+ F^0_{15}(1685)$
- 2π direct



Total $\pi^+\pi^-$ photoproduction cross-section off protons.

- $3/2^+(1720)$ photocouplings adjusted to the real photon data. Hadronic couplings and mass derived from the fit of virtual photon data.

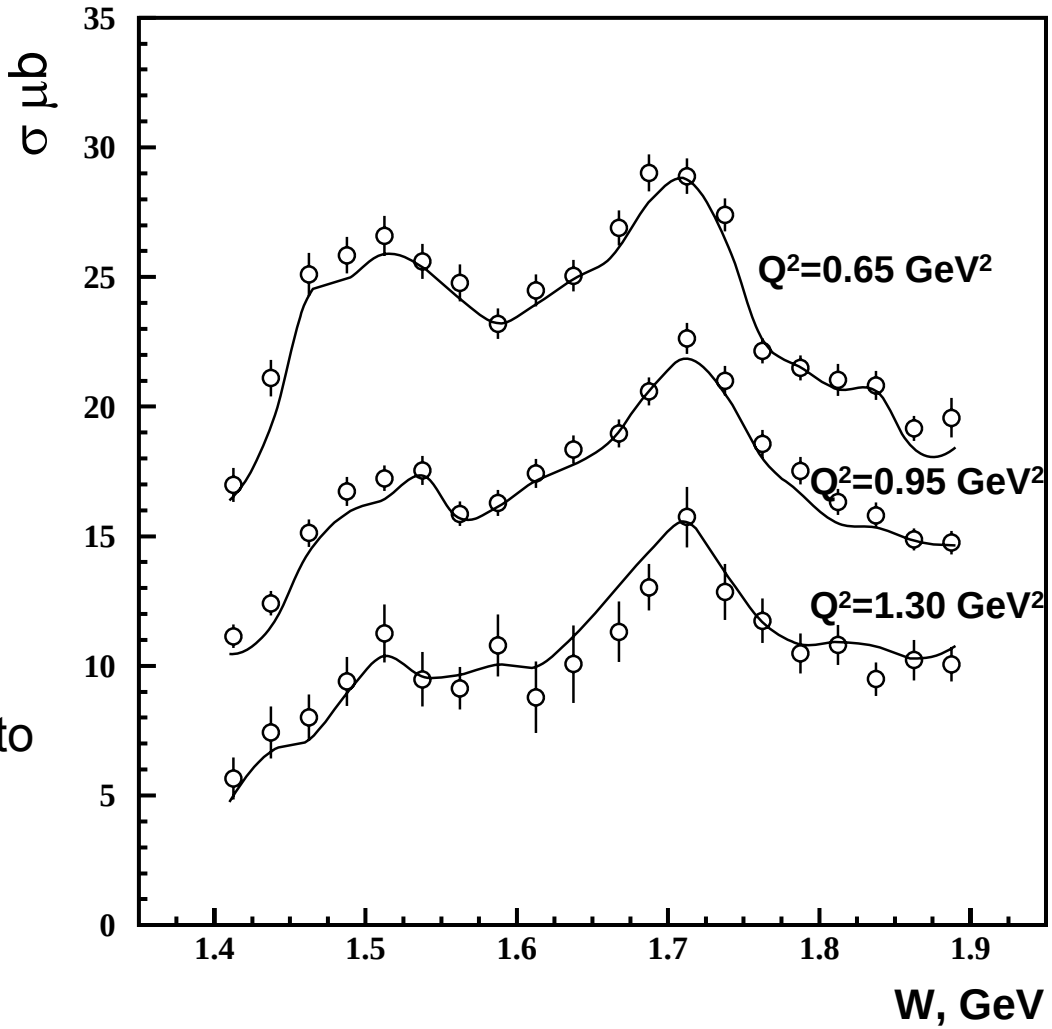
- Signal from $3/2^+(1720)$ state present, but masked by large background



Total $\pi^+\pi^-$ electroproduction cross-section off protons.

- Initial values of N* photocouplings were taken from analysis of CLAS 2π data within the framework of 2003'-version of the JLAB-MSU model: V.Burkert et.al., Nucl. Phys. A737, S231 (2004) and further adjusted to the data, using recent version of model.

- Signal from possible $3/2^+(1720)$ state ~ 1.7 GeV becomes more pronounced at $Q^2>0.5$ GeV^2 due to considerable growth of N*/Bckgr. ratio in electroproduction.



Improvements in the fit of the 2π CLAS electroproduction data after implementation of new non-resonant mechanisms

Q^2, GeV^2	0.65	0.95	1.30
χ^2/d.p. 2003'-version	3.91	3.30	2.26
χ^2/d.p. improved JLAB-MSU model	2.83	1.90	2.01

χ^2 was estimated from comparison between calculated and measured 1-diff. cross-sections for entire set of data in particular Q^2-bin

Quality of CLAS data allows to describe all relevant mechanisms of 2π production at W<1.9 GeV and Q^2<1.5 GeV^2 by meson baryon diagrams, fitting theirs parameter to the data without any need for residual mechanisms of unknown dynamics.

Essentials of JLAB-MSU model improvements are highlighted in:
V.Mokeev et. al., Proc of NSTAR2004 Workshop, World Scientific 2005 ed. by J.-P.Bocquet, V.Kuznetsov, D.Rebreyend, 317

Combined analysis of the CLAS data on 1π and 2π electroproduction

Data at Q^2=0.65 GeV^2 were analyzed. It is only photon virtuality for which both 1π and 2π CLAS data exist so far.

Single pion data: $d\sigma/d\Omega$ differential cross-sections:

CLAS 1π data
K.Joo, L.C.Smith, et.al

π+ at W between 1.1-1.41 GeV,
π^0 at W between 1.1-1.68 GeV;
beam asymmetries:
π^+ and π^0 at W between 1.1-1.58 GeV
9870 data points

Double pion data: $\pi^+\pi^-$, π^+p, π^-p mass and

CLAS 2π data
M.Ripani, V.D.Burkert, et.al.

CM π^- angular distributions at
W between 1.41-1.89 GeV
680 data points

The data are available in CLAS Physics DB: http://clasdb3.jlab.org

1π analysis models: I.G. Aznauryan, Phys. Rev. C68, 065204 (2003); I.G. Aznauryan, et. al., Phys. Rev. C71, 015201 (2005).

1π CLAS/world data fit (step 1).

All available data on single pion electroproduction were fitted within the framework of 1π dynamical model (see ref. on p.30).

- N* photocouplings were fitted to the CLAS data, using MINUIT minimization procedure. They were fixed at the values corresponded to single global minimum for χ^2/d.p.
- Photocoupling uncertainties were derived from error matrix, evaluated at minimal χ^2/d.p. They may be larger due to possibilities of comparable data description within uncertainties, corresponded to various χ^2/d.p. outside the global minimum.

2π CLAS data fit (step 2).

- N* photocouplings were fluctuated around values extracted in 1π data fit within 30% σ
- For each set of photocouplings all measured single differential 2π cross-sections were estimated within the framework of improved JLAB-MSU model and χ^2/d.p.'s were obtained from comparison with CLAS 2π data
- The sets of the N* photocouplings were selected, for which evaluated cross-sections are inside data uncertainties, applying restriction χ^2/d.p<3.0
- Mean values in samples of selected photocouplings were assigned to $A_{1/2}$, $A_{3/2}$ and $S_{1/2}$ form factors. Respective dispersions were treated as form factor uncertainties

N* photocouplings (in 10^{-3} GeV$^{-1/2}$) extracted in analyses of $1\pi/2\pi$ exclusive channels at Q^2=0.65 GeV^2

N*	1π-2π analysis (errors from procedure on p13)			1π analysis (lower boundary for errors)			2π analysis (errors from procedure on p.13)		
	$A_{1/2}$	$A_{3/2}$	$S_{1/2}$	$A_{1/2}$	$A_{3/2}$	$S_{1/2}$	$A_{1/2}$	$A_{3/2}$	$S_{1/2}$
$P_{11}(1440)$	21±4		33± 6	4± 4 (23±4)		40± 4	21± 9		35± 6
$D_{13}(1520)$	-65± 4	62± 5	-35± 3	-67± 3	62± 4	-38± 3	-63± 12	62± 11	-40± 7
$S_{31}(1620)$	16± 4		-28± 3	31± 3		-35± 3	13± 3		-25± 4
$S_{11}(1650)$	43± 7		-6± 3	43± 2		-15± 2	44± 16		-8± 2
$F_{15}(1680)$	-32± 5	51± 4	-15± 3	-38± 4	56± 2	-18± 2	-31± 8	52± 10	-14± 3
$D_{33}(1700)$	44± 4	36± 4	-7± 4	58± 5	29± 3	-15± 5	49± 8	36± 8	-11± 4
$D_{13}(1700)$	-21± 2	10± 1	0	-6± 8	-55± 7	0±8	-19± 3	11± 2	0
$P_{13}(1720)$	55± 3	-68 ±4	0	45± 6	-48± 7	0±7	56± 6	-62± 9	0

(…) result from dispersion relations. Roper is only state with $A_{1/2}$ dependent from model for 1π analysis

-The states with considerable 1π decays

Search for N* photocouplings compatible both with 1π and 2π CLAS data.

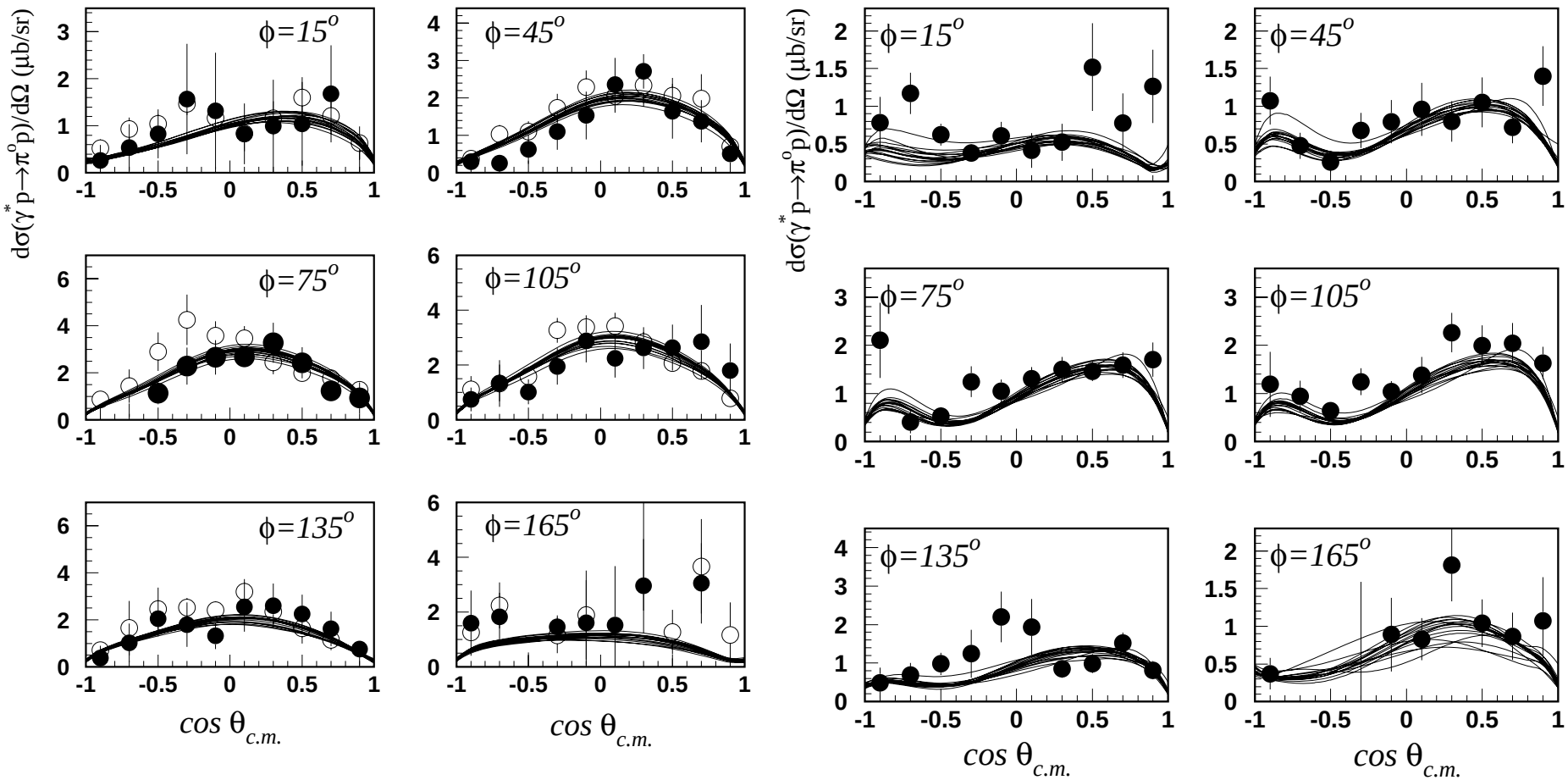
- N* photocouplings were varied inside uncertainties of 1π and 2π data fit for the states with major 1π and 2π decays respectively. Additional variation of πN BF within established uncertainties were applied. Common sets of N* electromagnetic/hadronic couplings were used to calculate 1π/2π differential cross-sections and LT' structure functions for π^+n and π^0p exclusive channels. I.G.Aznayuryn dynamical model JANR were applied for analysis of 1π channels. Recent improved version of JLAB-MSU model was used for analysis of $\pi^-\pi^+$p channel. Calculated observables were compared with recent CLAS 1π/2π data.
- Sub-sets of N* photocouplings were selected, for which calculated observables both in 1π/2π channels were inside data uncertainties. For selected sub-sets of calculated observables χ^2 per data point span between 1.24-1.20 (1π channels) and 2.82-2.95 (2π channel)
- Selected sub-sets of N* photocouplings, which provided good reproduction of both 1π and 2π data, were averaged for each state and mean values were treated as extracted from combined 1π/2π analysis, while their dispersions were considered as errors. The results are given in the Table (see p. 33)

1π data description with N* photocouplings from combined analysis of 1π/2π channels.

W=1.52 GeV

$\gamma_v p \rightarrow \pi^0 p$

W=1.68 GeV



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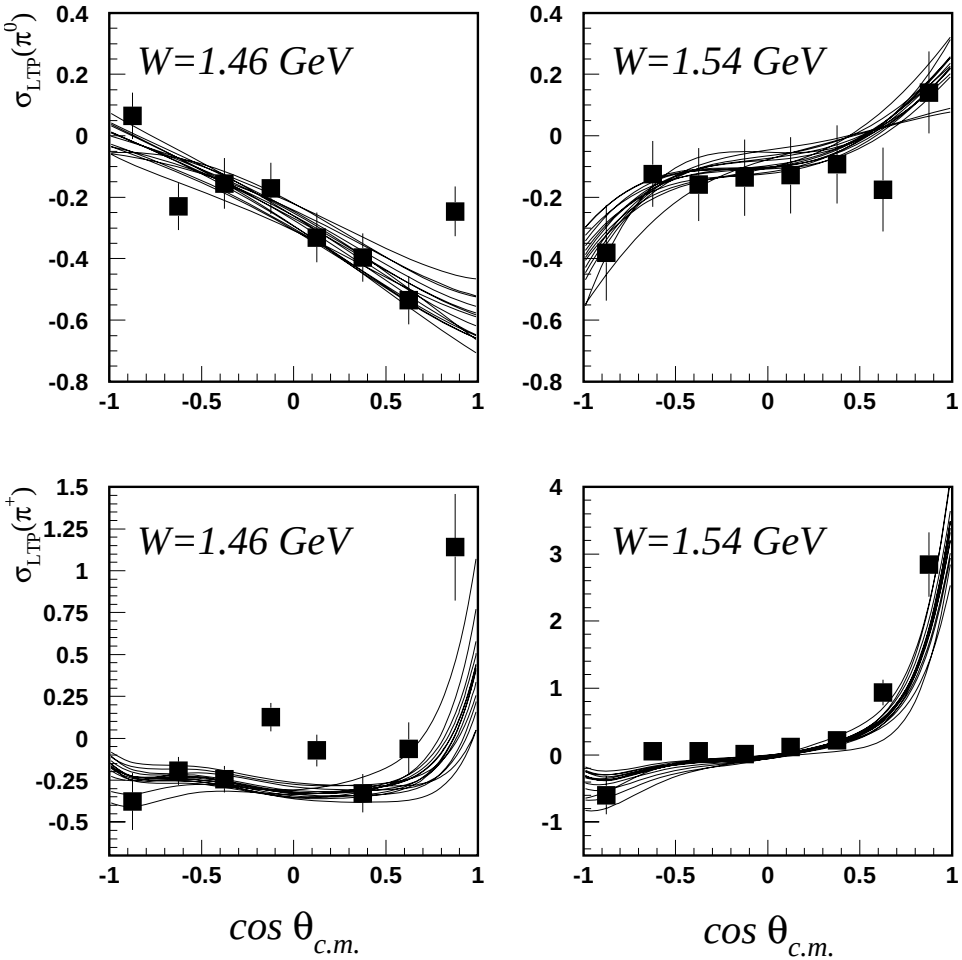
$\gamma_v p \rightarrow \pi^0 p$

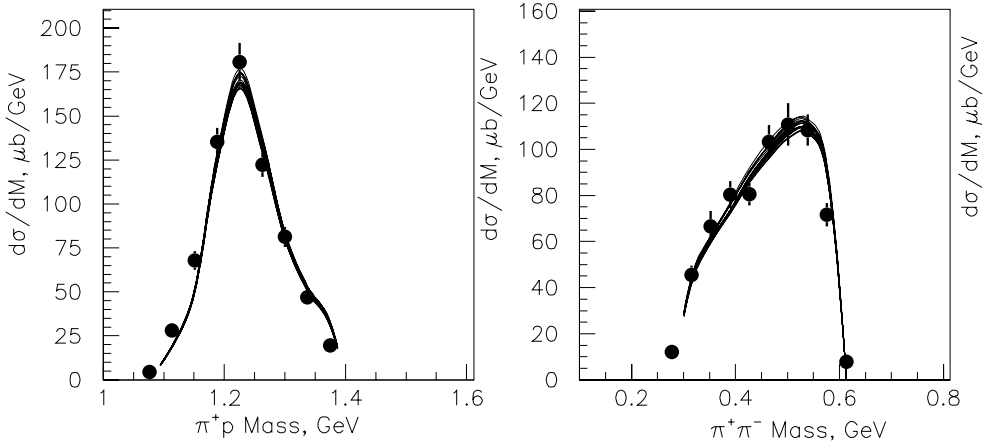
$\sigma_{LT'}$

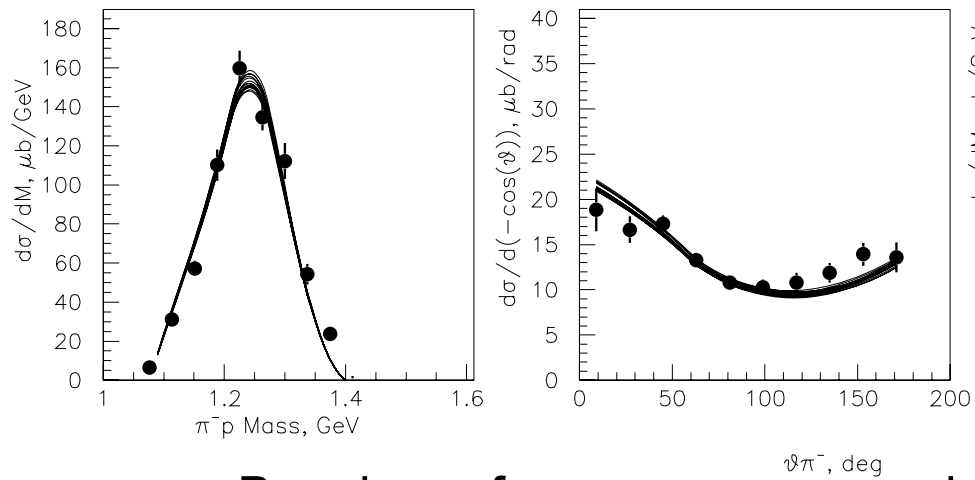
All observables in 1π channel, measured with CLAS, as well as world data at Q^2=0.65 GeV^2 were described pretty good in JANR model, using sets of N* photocouplings, derived in combined 1π-2π analysis



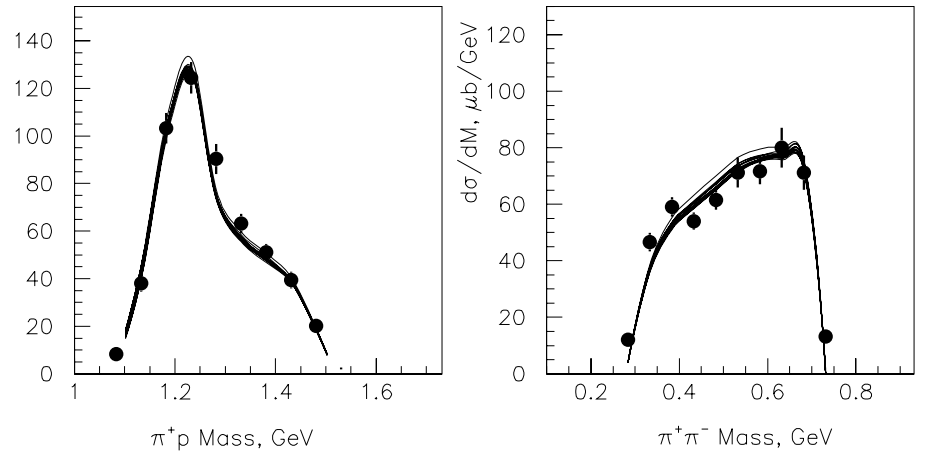
2π data description with N* photocouplings from combined analysis of 1π/2π channels.

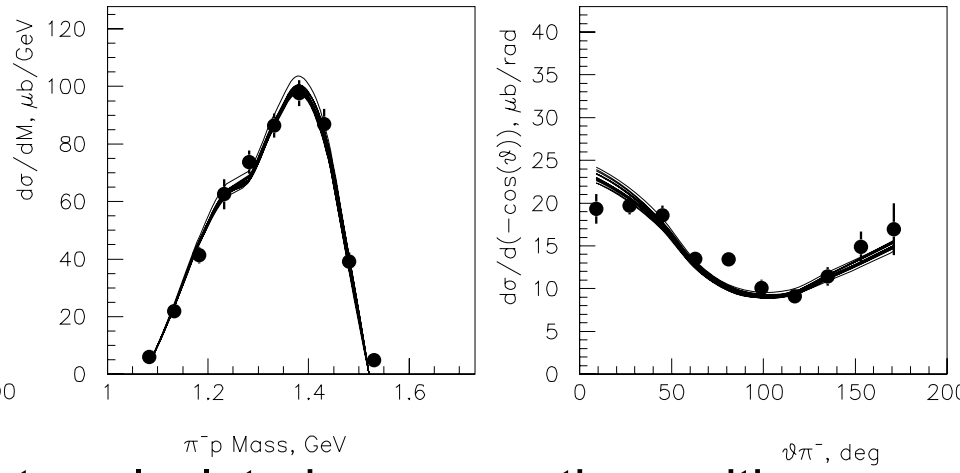
W=1.54 GeV Q^2=0.95 GeV^2





W=1.66 GeV Q^2=0.95 GeV^2

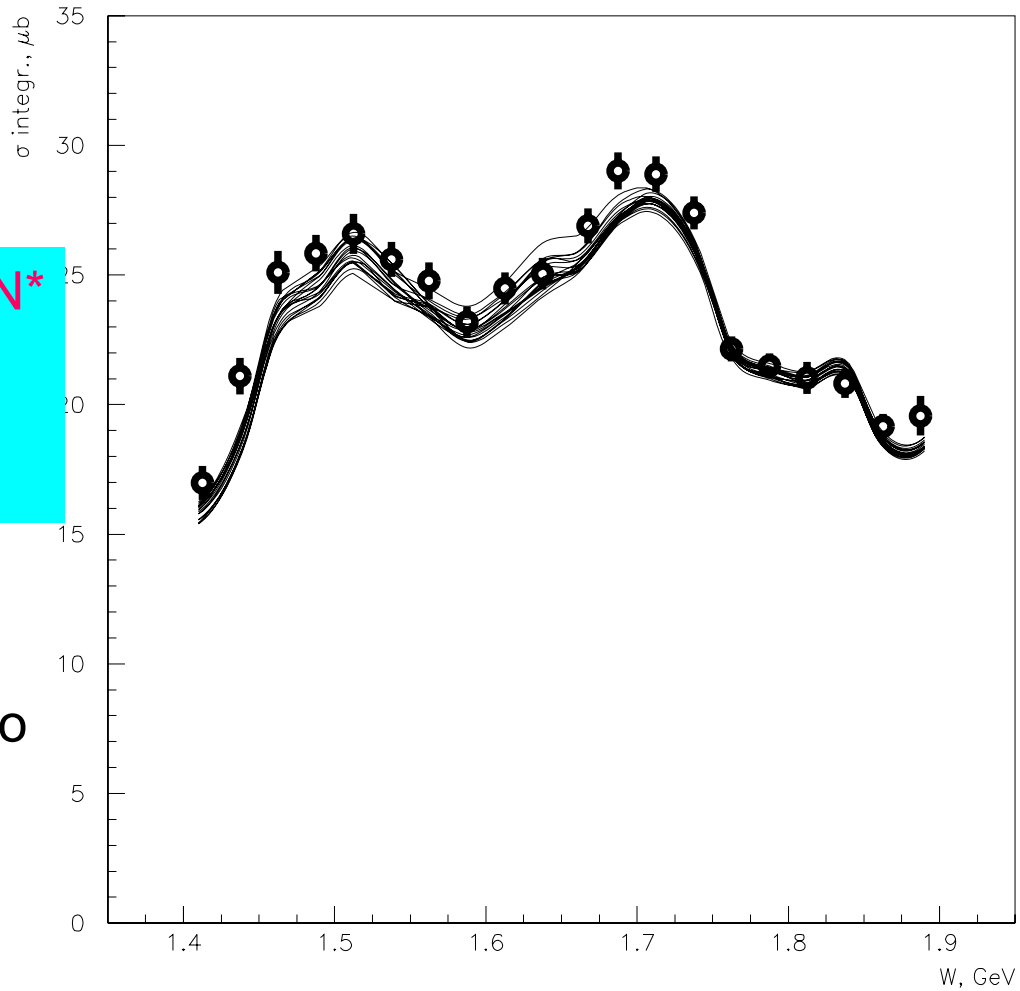




Bunches of curves correspond to calculated cross-sections with common sets of N* photocouplings

Con't

Integrated 2π cross-section
Q^2=0.65 GeV^2



Calculations with common sets of N* photocouplings provided good description of all available 2π cross-sections at Q^2=0.65 GeV^2

The results are presented in:
I.G.Aznauryan et. al., submitted to Phys. Rev. C., hep-ph/0508057

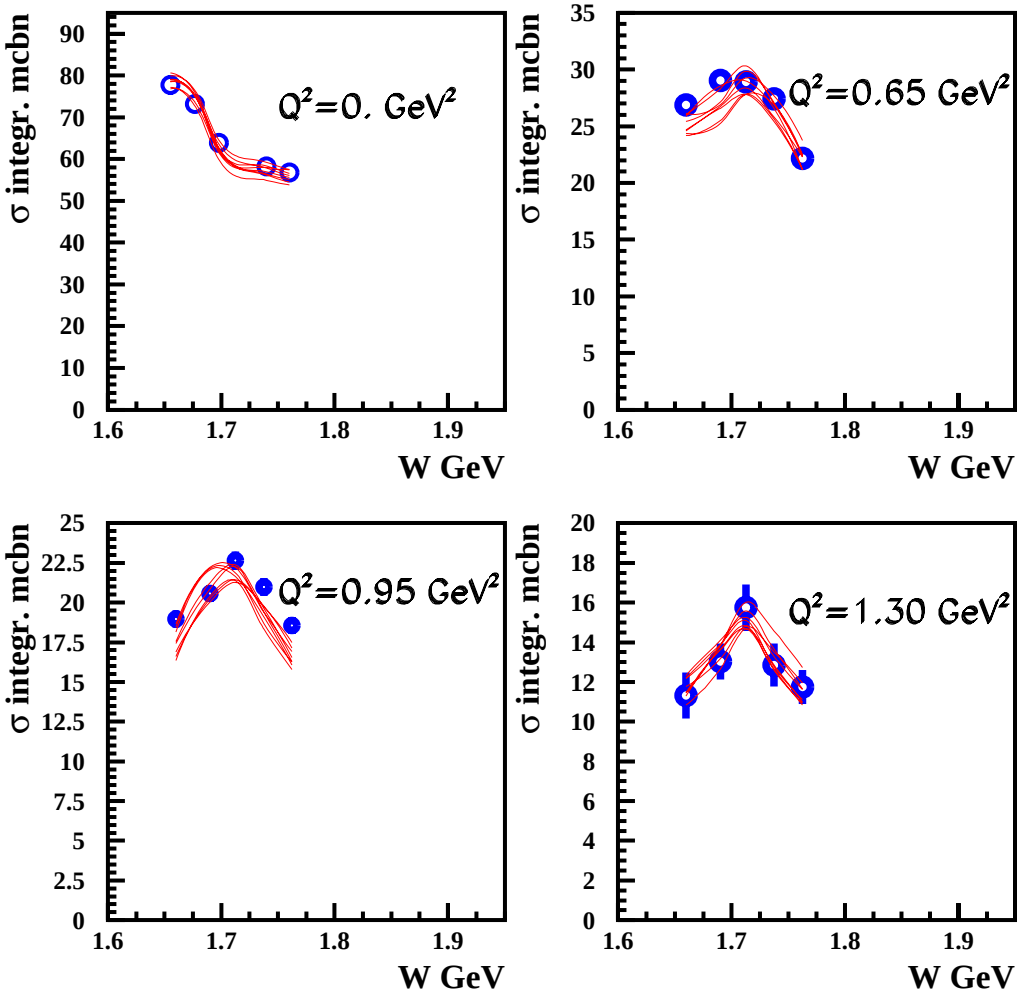
Q^2-evolution of N* photocouplings from analysis of the CLAS 2π data.

- Double pion data: $\pi^+\pi^-$, π^+p, π^-p mass and CM π^- angular distributions at W between 1.41-1.89 GeV and photon virtualities Q^2 0., 0.65, 0.95, 1.30 GeV^2, available in CLAS Physics DB: http://clasdb3.jlab.org.
- All 4 Q^2 bins were fitted combined within a framework of recent vesion of JLAB-MSU model. Fitting procedure was applied separately in W-intervals between 1.41-1.51 GeV, 1.54-1.64 GeV, 1.66-1.76 GeV, 1.79-1.89 GeV
- Photocoupling and poorly known $\pi\Delta$ and ρp couplings of N* were varied and fitted to the data together with parameters of non-resonant mechanisms implemented in improved JLAB-MSU model. Hadronic couplings were further constrained by requirement of their Q^2-independence. The photocouplings and hadronic parameters were derived from data fit in a way similar to described on p. 32

W area between 1.66-1.76 GeV. Total $\pi^+\pi^-p$ cross-sections.

Photocouplings and poorly known hadronic $\pi\Delta$ and ρp couplings of the states P33(1600), S31(1620), S11(1650),F15(1680),D13(1700), D33(1700), P13(1720) as well as of possible new $3/2^+(1720)$ were fit to the data together with parameters of new non-resonant mechanisms

$1.75<\chi^2/d.p.<2.05$

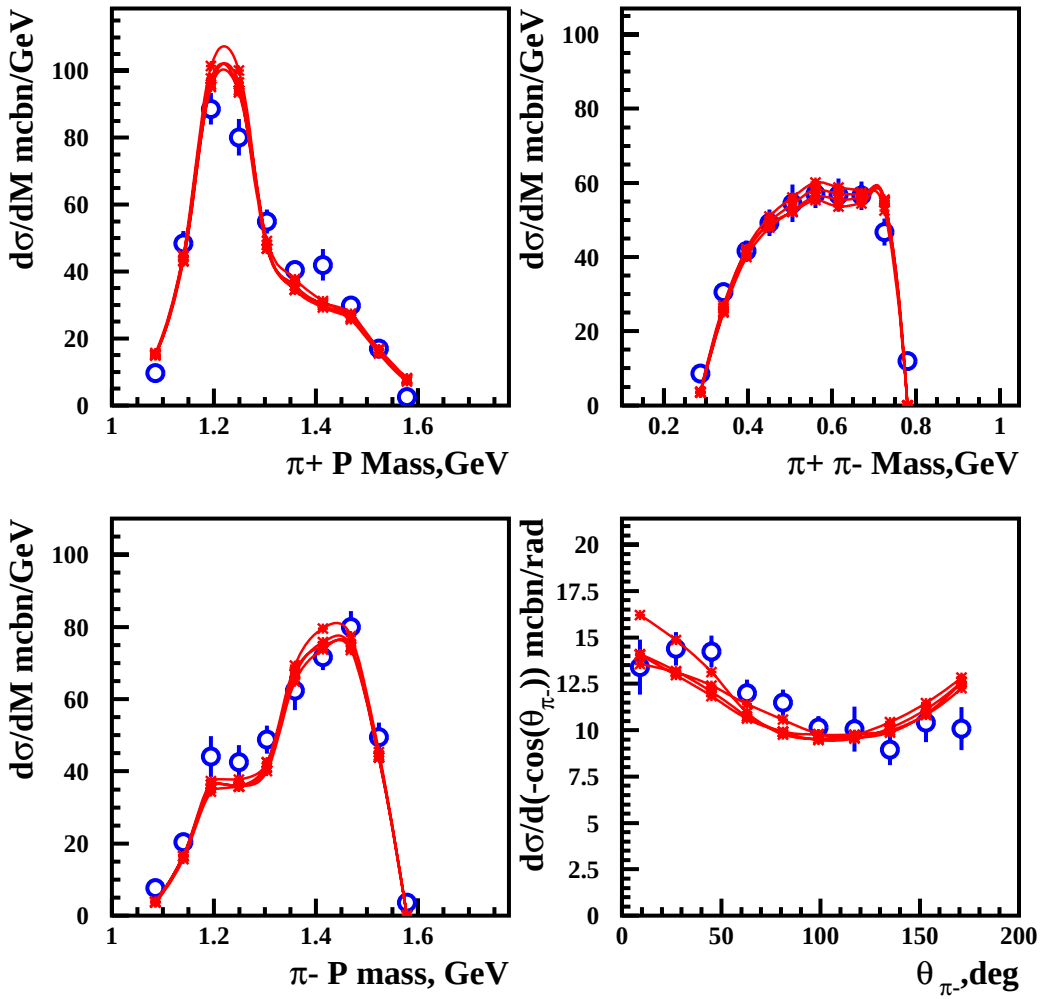


Description of single-differential cross-sections with selected sets of variable parameters.

Bunches of curves correspond to calculated cross-sections, applying restriction $\chi^2<2.05$

Similar sets of observables were fit in all available W and Q^2bins shown on previous slide

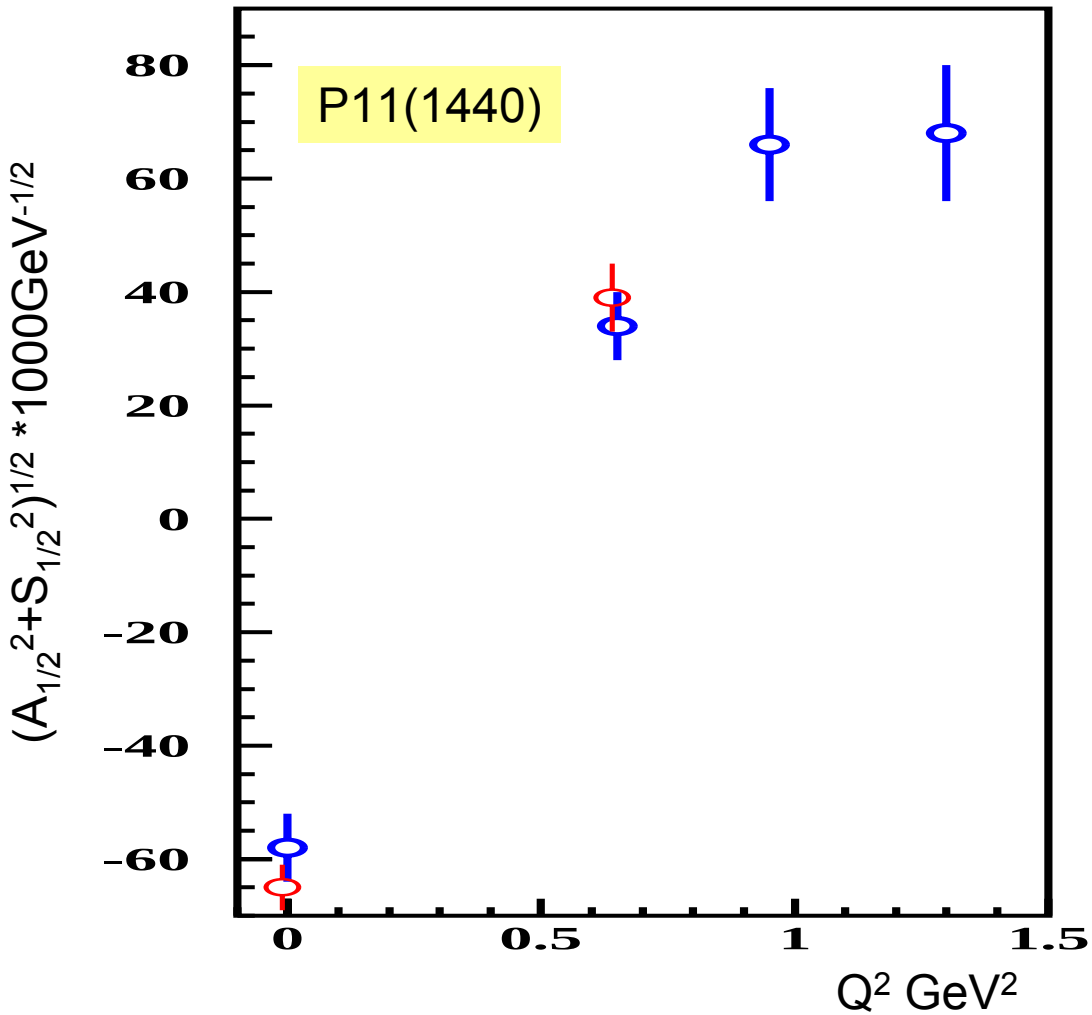
W=1.71 GeV and Q^2=0.95 GeV^2



Q^2-evolution of the photocouplings for N*'s in mass range between 1.40-1.80 GeV, determined from analysis of CLAS 2π data.

CLAS 2π data analysis

PDG at Q^2=0 GeV^2; 1π-2π combined CLAS data analysis at Q^2=0.65 GeV^2



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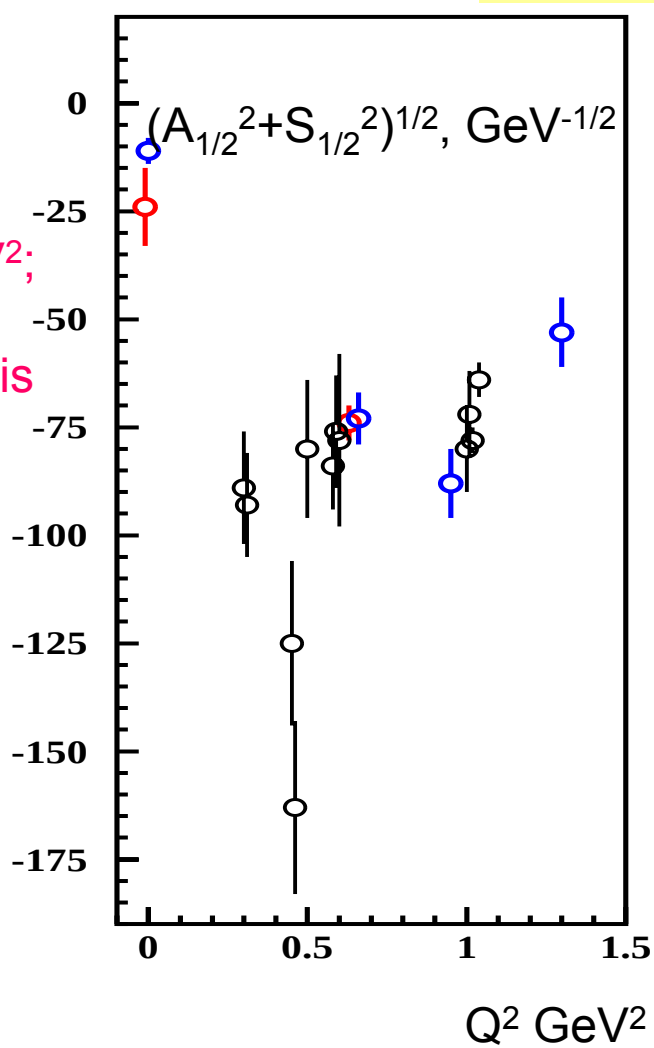
D13(1520)

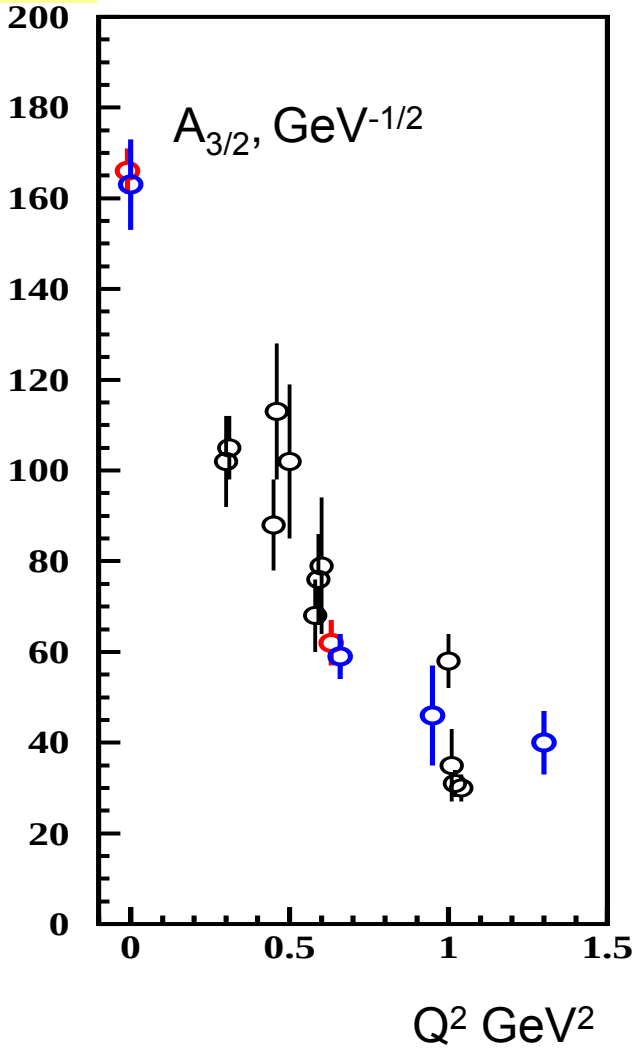
CLAS 2π data analysis

PDG at Q^2=0 GeV^2; 1π/2π combined CLAS data analysis at Q^2=0.65 GeV^2

World data before CLAS, obtained in analysis of 1π electroproduction:

V.D. Burkert, et. al., Phys. Rev. C67, 035204 (2003)





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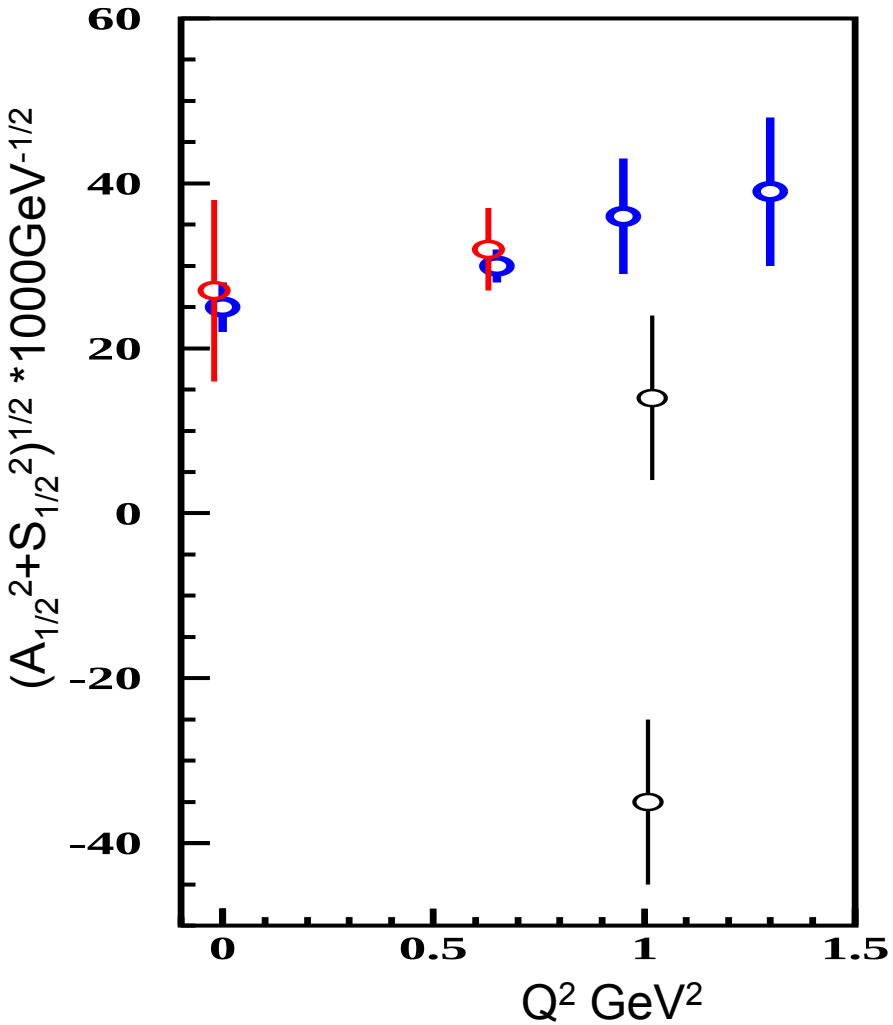
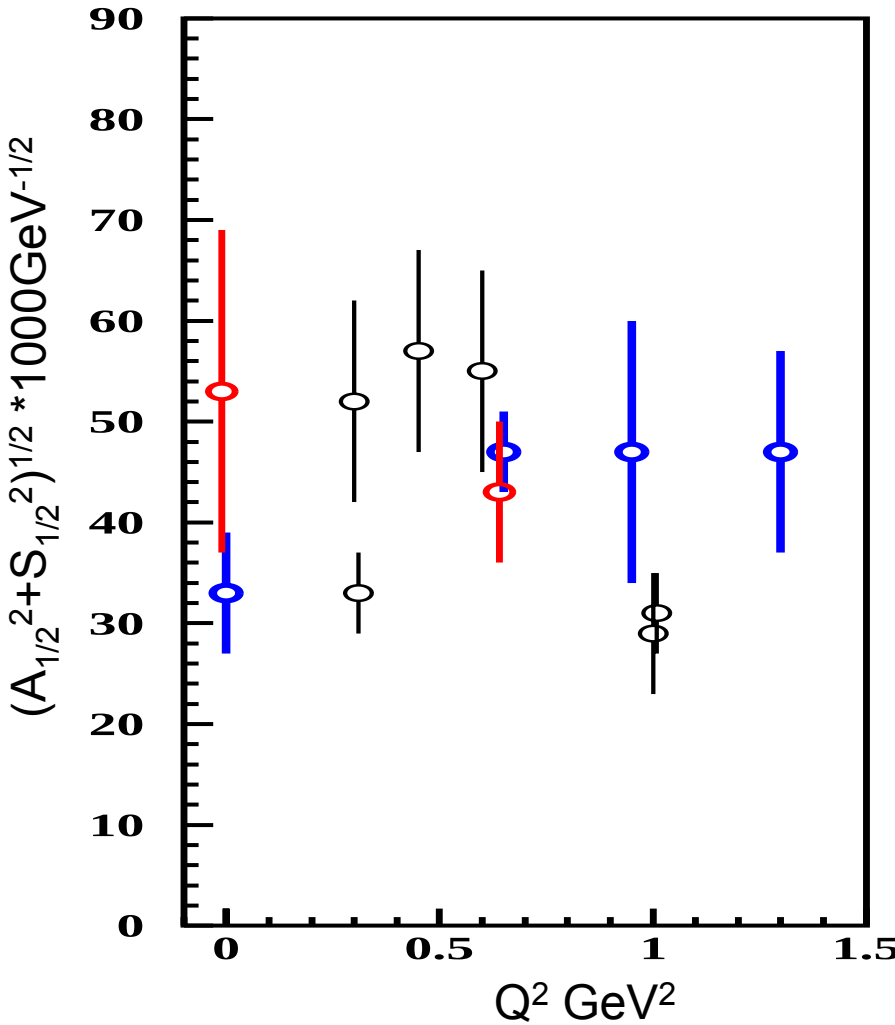
S31(1620)



S11(1650)



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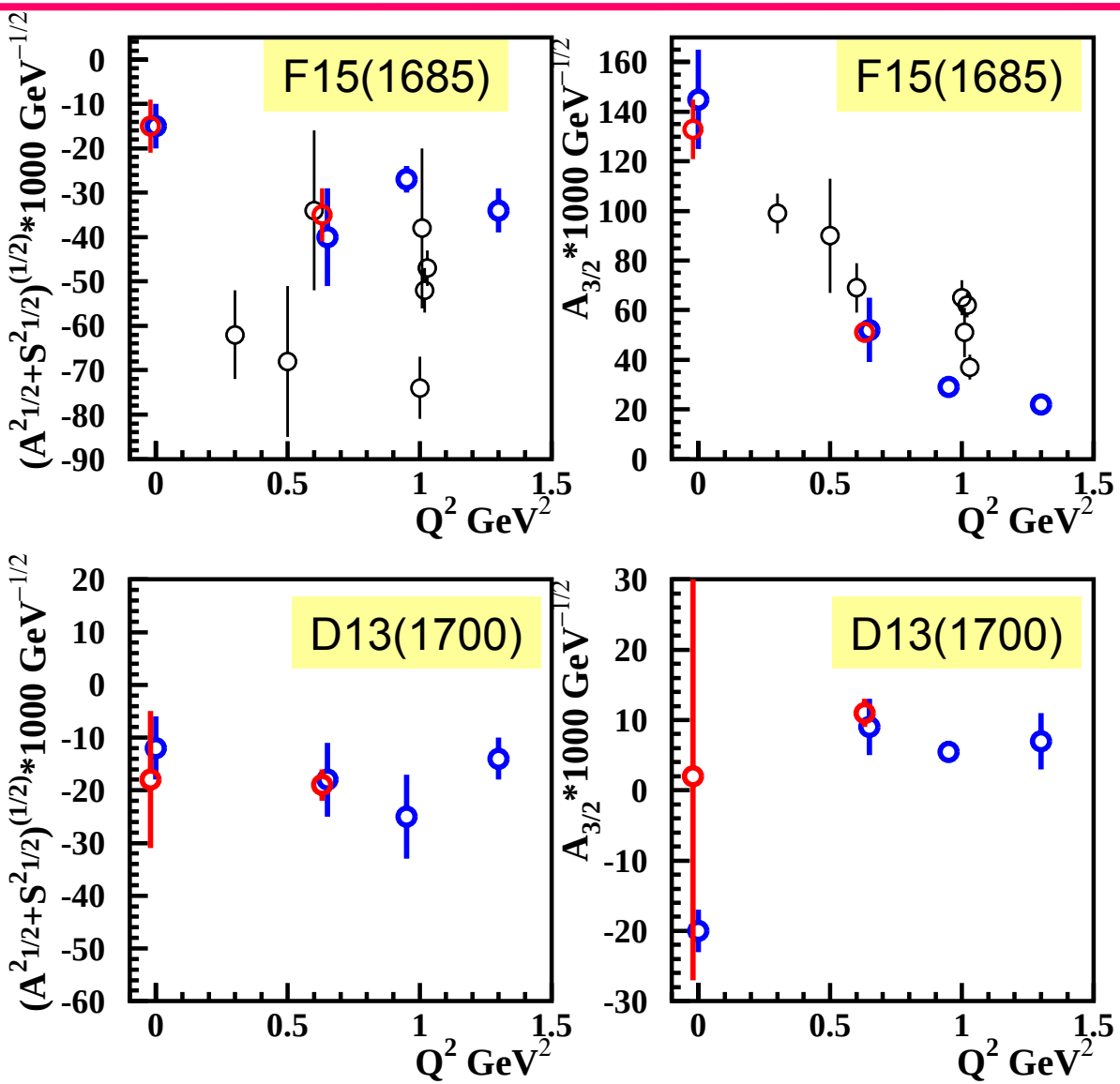
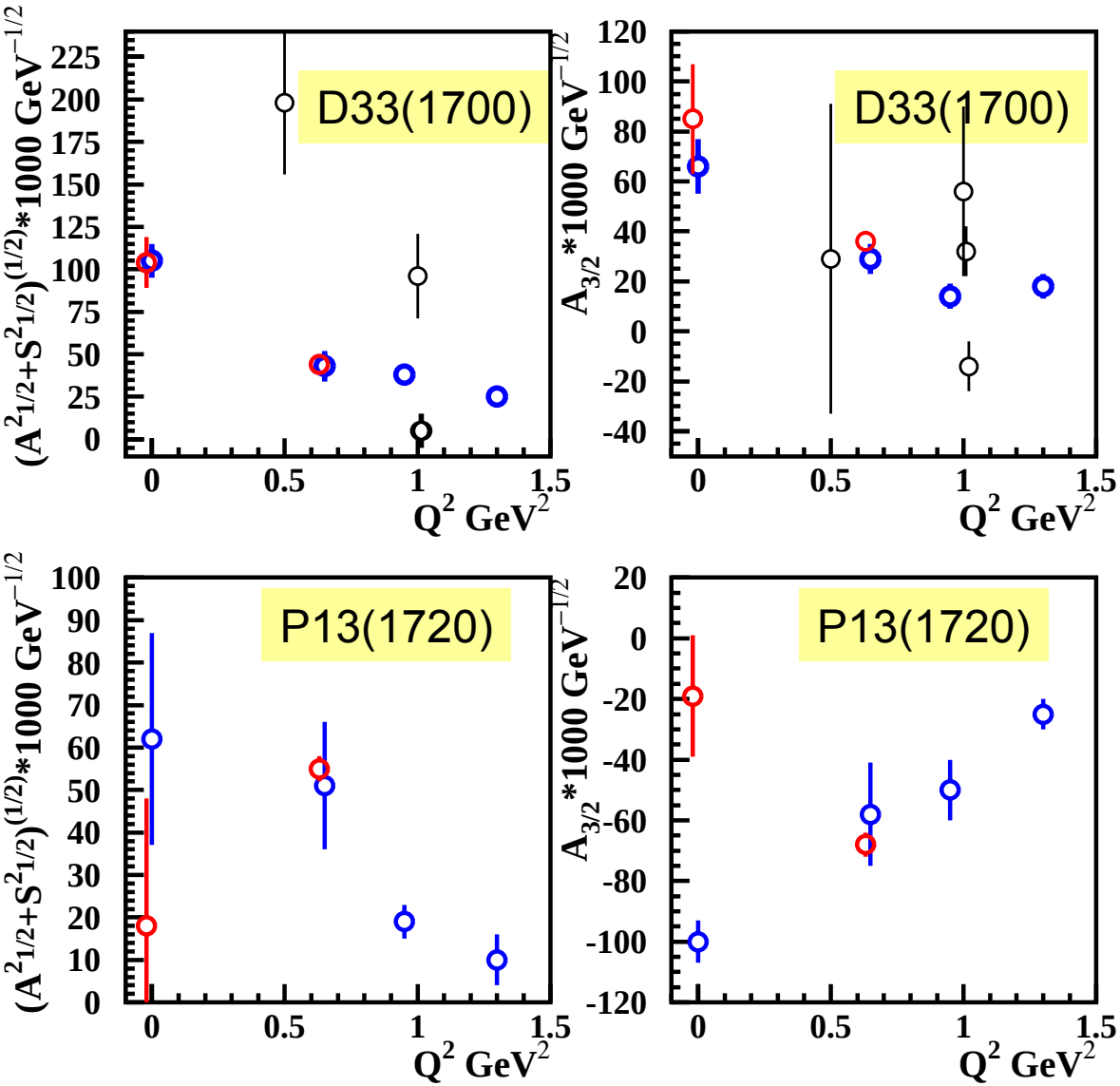

F15(1685)
F15(1685)
D13(1700)
D13(1700)
$(A^2_{1/2}+S^2_{1/2})^{(1/2)}*1000\ GeV^{-1/2}$
$A_{3/2}*1000\ GeV^{-1/2}$
$Q^2\ GeV^2$

Cont'd

S31(1620), D13(1700), D33(1700), P13(1720) resonances mostly decay with 2π emission. 1π world data before CLAS at $Q^2>0$ (black points) have no enough sensitivity to these states.

First data on Q^2-evolution of S31(1620), D13(1700), D33(1700), P13(1720) photocouplings were obtained from analysis of CLAS experiments on 2π photo- and electro-production.

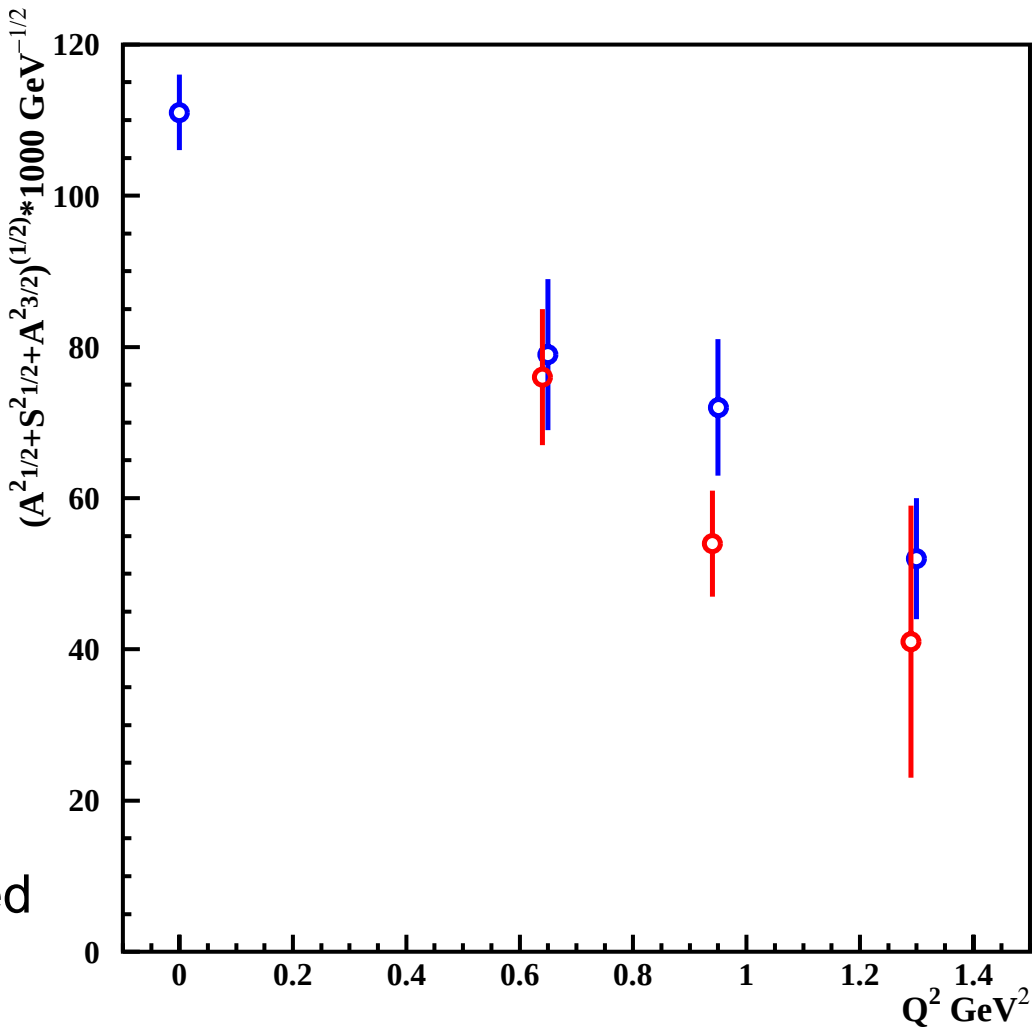


Possible new baryon state $3/2^+(1720)$.

recent CLAS 2π data analysis

previous analysis of CLAS data on 2π electro- production

Signal from possible new baryon state was confirmed in analysis of electro-production data and observed in real photon data.



Conclusion.

- Phenomenological approach was developed for description of 2π production by real and virtual photons in N* excitation region and for the photon virtualities $Q^2<1.5$ GeV^2 with most complete treatment of all relevant mechanisms. The approach allow to determine N* photocouplings and, in part, hadronic parameters fitting them to all measured observables in $\pi^+\pi^-p$ final state.

- Quality of CLAS data allowed to describe all relevant 2π production mechanisms, implementing particular meson-baryon diagrams needed for data fit. Good description of all unpolarised CLAS/world data was achieved without any need for remaining mechanisms of unknown dynamics. Reliability of background description and N*/background separation was confirmed in combined analysis of CLAS 1π and 2π electroproduction data.

- The photocouplings in Q^2-area between 0 and 1.5 GeV^2 were extracted from CLAS 2π photo- and electroproduction data for most N*' with masses less then 1.8 GeV. For the first time data on Q^2-evolution of the photocouplings were obtained for the states S31(1620), D13(1700), D33(1700), P13(1720).

- Combined analysis of recent CLAS 2π photo- and electroproduction data revealed further evidences for possible new baryon state $3/2^+(1720)$, reported for the first time by CLAS Collaboration.

Outlook

- Comprehensive data on photocouplings for an entire proton excitation spectrum in a wide Q^2-range may allow:

  a) establish driving symmetry of non-perturbative strong interactions, responsible for N* formation;

  b) access N* structure in terms of contributing quark configurations;

  c) fit shape of 3q binding potential to N* photocouplings and further, using dynamical models, to the observables measured in $1\pi/2\pi$ exclusive channels. Determined in this way confining potential may be confronted to the expectation from fundamental QCD, exploiting lattice simulations.
- Input on various 2π production mechanisms at amplitude level may be provided for N* studies within the framework of rigorous coupled channel approaches.
- First comprehensive data on N* photocoupling evolution with Q^2 offer most reliable estimation of the resonant parts in inclusive structure functions. The data on resonance contribution in inclusive processes are important in the studies of quark distributions and hadronization at high x-Bjorken as well as for understanding of quark-hadron duality.