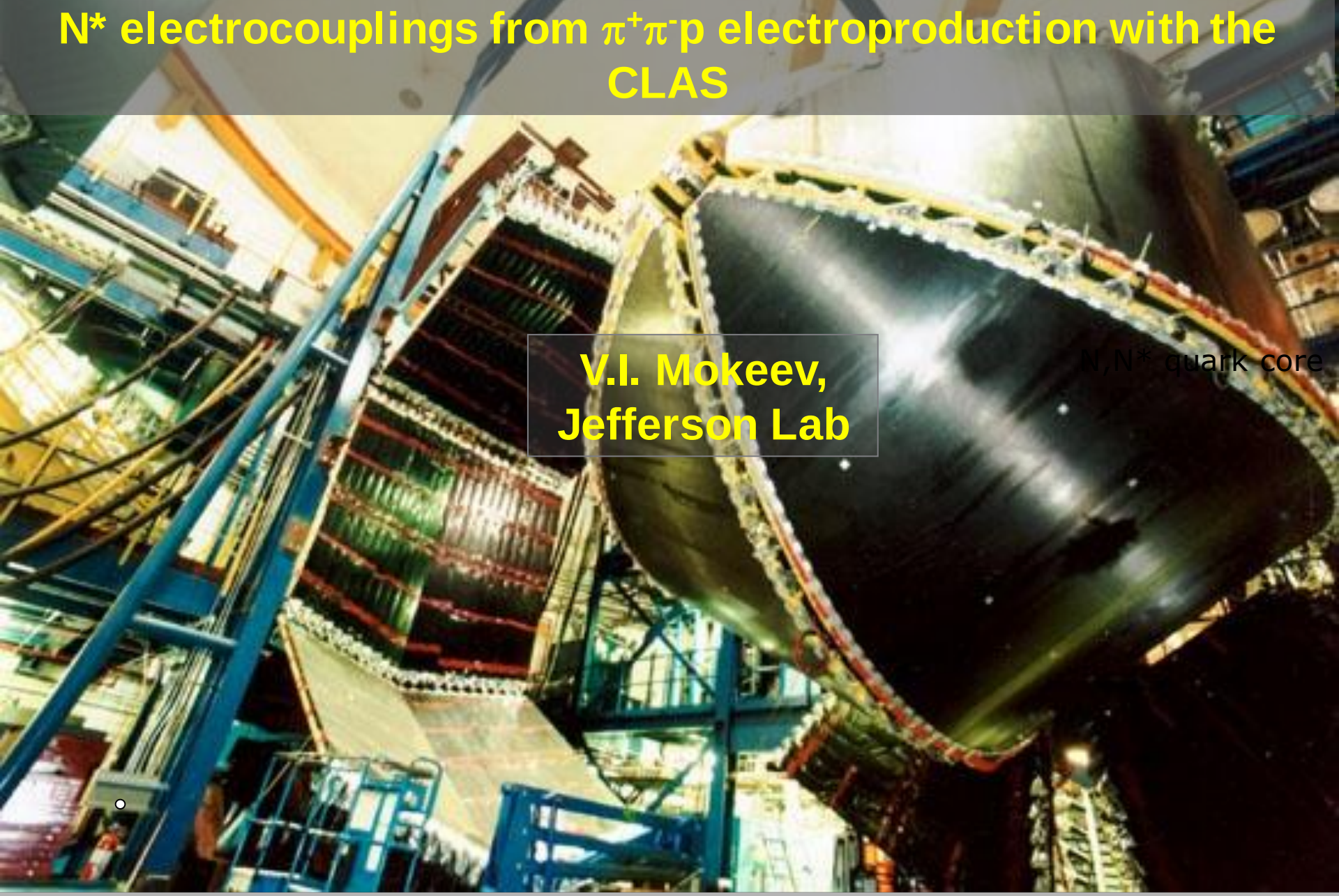
N* electrocouplings from $\pi^+\pi^-$p electroproduction with the CLAS



V.I. Mokeev,
Jefferson Lab

N,N* quark core

FDSA 2014 Workshop

The Major Objectives in the Studies of the N*-Structure

The experimental program on the studies of N* structure in exclusive meson electroproduction with CLAS seeks to determine:

- $\gamma_v NN^*$ electrocouplings at photon virtualities up to 5.0 GeV^2 for most of the excited proton states through analyzing major meson electro-production channels independently and in global multi-channel analyses;
- extend available knowledge on resonance hadronic decays in particular for the multi-meson final states.

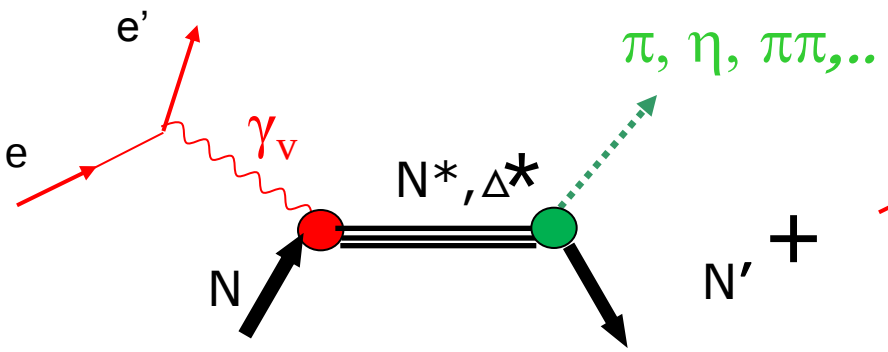
- **Access to relevant degrees of freedom in the N* structure and their evolution with distance;**
- **A unique source of information on different manifestations of non-perturbative strong interaction in generating different excited nucleon states as relativistic bound systems of quarks and gluons.**

The review papers:

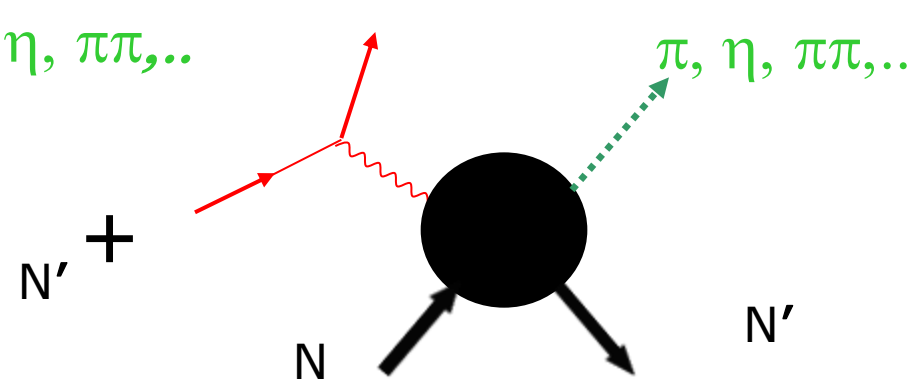
1. **I.G. Aznauryan and V.D.Burkert, Progr. Part. Nucl. Phys. 67, 1 (2012).**
2. **I.G. Aznauryan et al., Int. J. Mod. Phys. E22, 133015 (2013).**
3. **I.C. Cloët and C.D. Roberts Prog. Part. Nucl. Phys. 77, 1 (2014).**

γ_vNN* Electrocouplings from the Exclusive Meson Electroproduction Data

Resonant amplitudes



Non-resonant amplitudes



- Real $A_{1/2}(Q^2)$, $A_{3/2}(Q^2)$, $S_{1/2}(Q^2)$
  or
- $G_1(Q^2)$, $G_2(Q^2)$, $G_3(Q^2)$
  or
- $G_M(Q^2)$, $G_E(Q^2)$, $G_C(Q^2)$

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

Definition of N*'s photo-/electrocouplings employed in the CLAS data analyses :

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

$$K=\frac{W^2-M_N^2}{2M_N} \qquad q_c=\frac{W^2-M_N^2}{2W}$$

$\Gamma\gamma$ stands for N* elrctro-magnetic decay widths at $W=M_{N^*}$ in real energy axis.

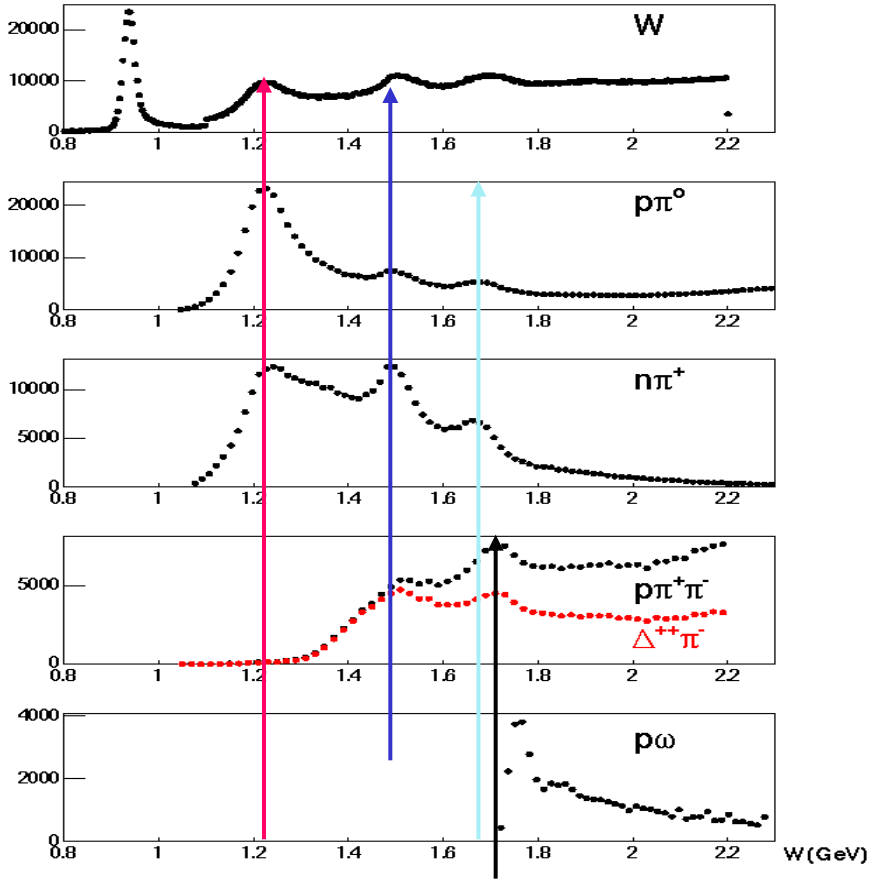
- **Consistent results on γ_vNN* electrocouplings from different meson electroproduction channels and different analysis approaches demonstrate reliable extraction of these quantities.**
- **It remains to be seen how the aforementioned γ_vNN* electrocouplings are related to their values provided by amplitude analyses from the residues at the N* pole positions.**

N* Electroexcitation in Exclusive Meson Electroproduction off Protons

Hadronic decays of prominent N*s at W<1.8 GeV.

State	Bran. Fract. to Nπ.	Bran. Fract. to Nη	Bran.Fract. Nππ
$\Delta(1232)P_{33}$	0.995		
$N(1440)P_{11}$	0.55-0.75		0.3-0.4
$N(1520)D_{13}$	0.55-0.65		0.4-0.5
$N(1535)S_{11}$	0.48±0.03	0.46±0.02	
$\Delta(1620)S_{31}$	0.20-0.30		0.70-0.80
$N(1650)S_{11}$	0.60-0.95	0.03-0.11	0.1-0.2
$N(1685)F_{15}$	0.65-0.70		0.30-0.40
$\Delta(1700)D_{33}$	0.1-0.2		0.8-0.9
$N(1720)P_{13}$	0.1-0.2		> 0.7

CLAS data on yields of meson electroproduction at Q^2<4 GeV^2

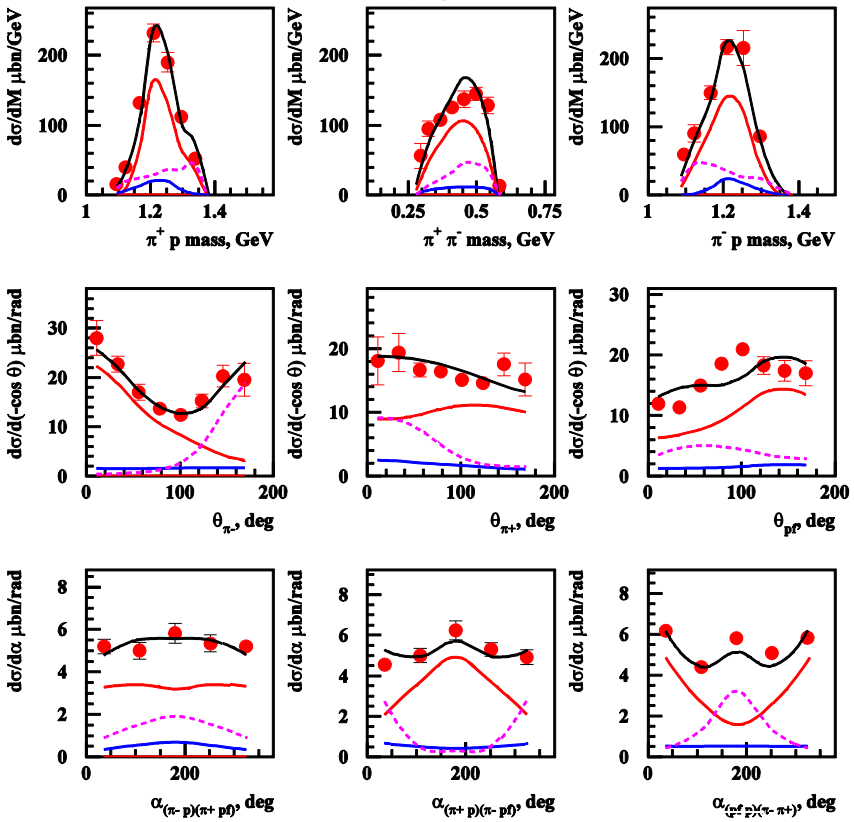


$\pi^+\pi^-$p electroproduction offers a preferential way to explore electrocouplings of high lying N* (M_{N^*}>1.6 GeV) and to check electrocouplings from Nπ electroproduction in independent analysis of other major exclusive channel.

The CLAS Data on $\pi^+\pi^-p$ Differential Cross Sections and their Fit within the Framework of Meson-Baryon Model JM

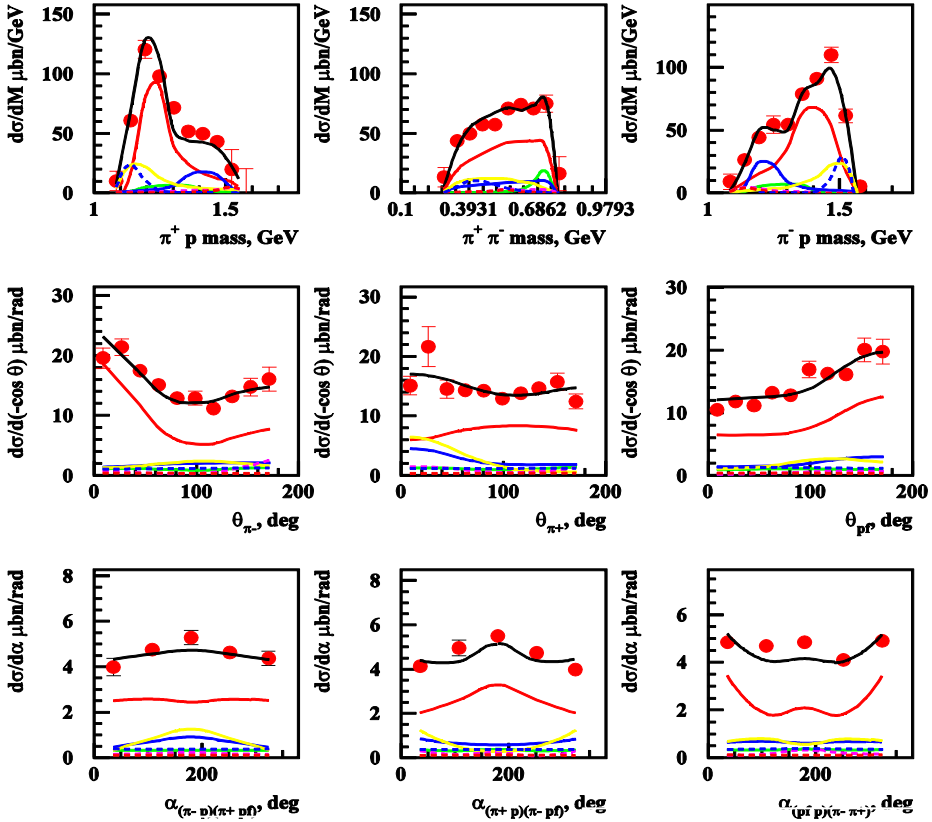
G.V.Fedotov et al, PRC 79 (2009), 015204
1.30<W<1.56 GeV; 0.2<Q^2<0.6 GeV^2

W=1.5125 GeV, Q^2=0.375 GeV^2



M.Ripani et al, PRL 91 (2003), 022002
1.40<W<2.30 GeV; 0.5<Q^2<1.5 GeV^2

W=1.71 GeV, Q^2=0.65 GeV^2

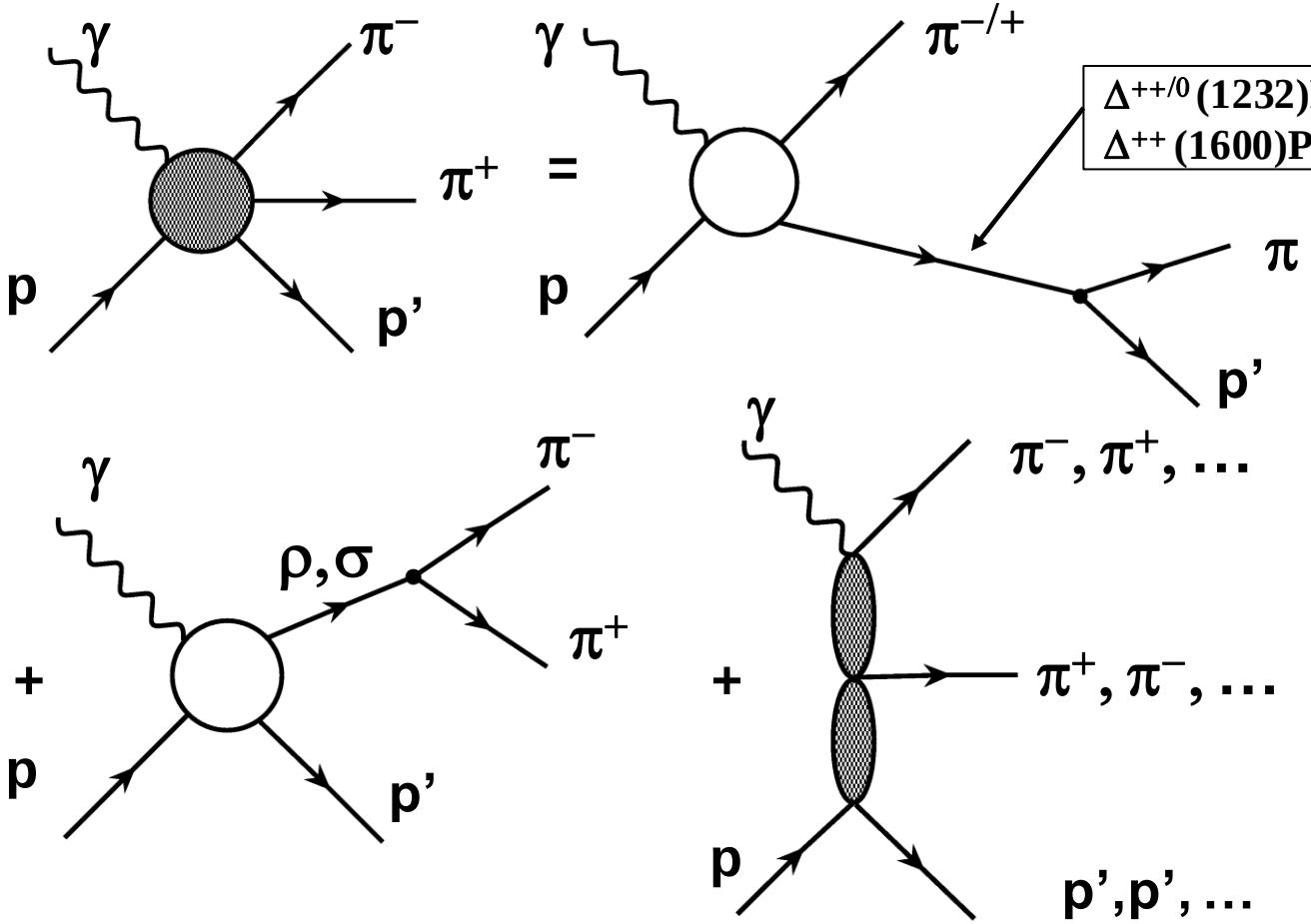


full JM calc. — $\pi^+\Delta^0$ — ρp ------- $\pi^+ N^0(1680)\ F_{15}$

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

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

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

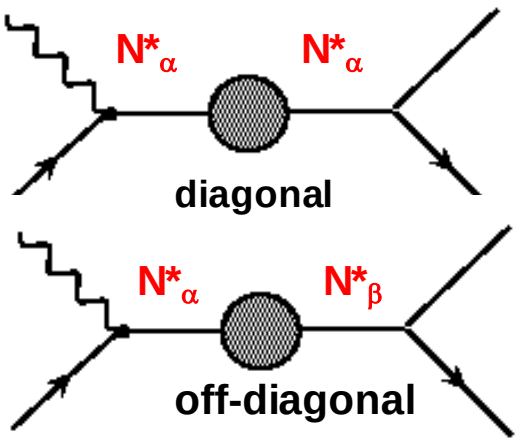


- seven channels with unstable intermediate meson/baryon and direct $\pi^+\pi^-p$ production;
- N* contribute to $\pi\Delta$ and ρp channels only;
- unitarized Breit-Wigner ansatz for resonant amplitudes;
- subtraction of partial waves with resonance contributions from non-resonant amplitudes (in progress).

•V.I.Mokeev, V.D. Burkert, et al., (CLAS Collaboration) Phys. Rev. C86, 035203 (2012).
•V.I.Mokeev, V.D. Burkert , et al., Phys. Rev. C80, 045212 (2009).

Unitarized Breit-Wigner Ansatz for Resonant Amplitudes

Resonant amplitude : $T^{res}_{\gamma p \to MB} = f_{\beta MB} S_{\alpha\beta} f_{\alpha\gamma p}$



Inverse of the JM unitarized N* propagator:

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

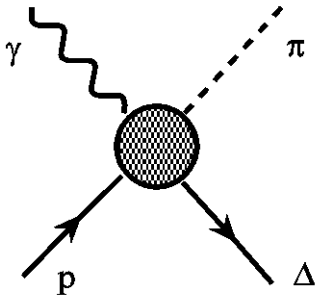
Off-diagonal transitions incorporated into the full resonant amplitudes of the JM model:

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

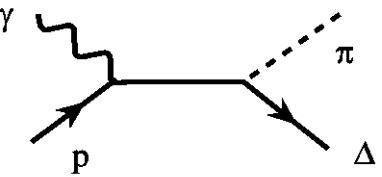
Full resonant amplitude of unitarized Breit-Wigner ansatz is consistent with restrictions imposed by a general unitarity condition. See details in Ref. 1 in the slide # 6

Non-resonant Contributions to πΔ Channels

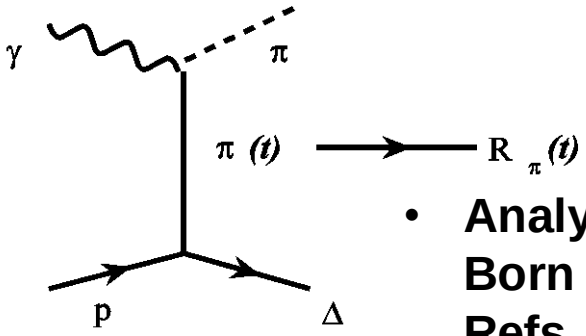
Minimal set of current conserving Born terms:



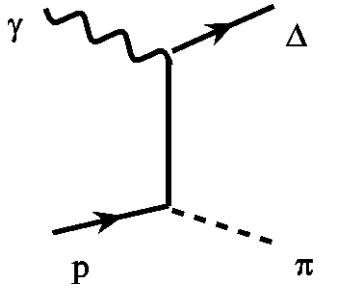
contact



nucleon term



pion in flight



delta in flight

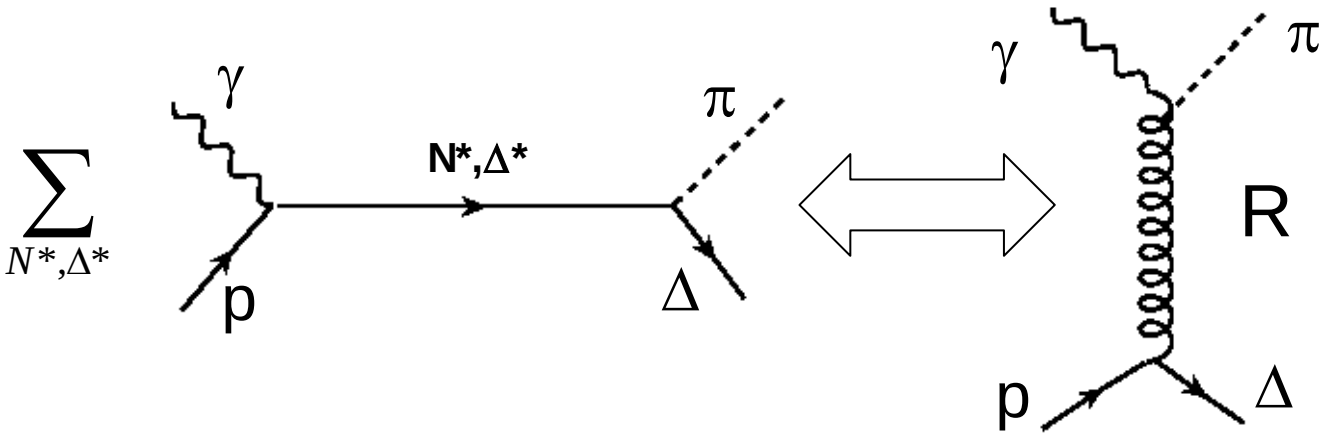
- **Analytical expressions for the Born terms can be found in Refs. 2 in the slide #6.**
- **Born terms were reggiezed , current conservation was kept, and extra contact term was added accounting for other contributions (See Ref. 2 in the slide # 6).**

Effective FSI treatment in πΔ channels. (M.Ripani et al., Nucl Phys. A672, 220 (2000).)

Request for theory support : evaluation of the FSI in πΔ,ρp meson-baryon channels employing the relevant coupled channel approaches.

Eliminating double counting in $\pi\Delta$ amplitudes

The recent updates proposed by A.P.Szczepaniak and M.R.Pennington



The contributions from all N*,Δ* resonances to s-channel and t-channel are dual (G.Veneziano, Nuovo Cimento 57A, 190 (1968)) ⇨

Possibility for double counting of resonant contributions to s -channel and pion-Regge-trajectory.

Prescription to eliminate double counting:
Subtract the partial waves originated by reggeized π-in-flight term with total angular momenta equal to spins of N*s contributing to s-channel.

At W<1.8 GeV, where only N*-states of spins <7/2 contribute, the partial waves of total angular momenta J=1/2,3/2,5/2 from reggized p-in-flight-term were subtracted.

The subtraction procedure employed for πΔ amplitudes in the JM model

Reggeized π-in-flight term $f_{\lambda\mu}$ and full unsubtracted Born amplitude $f_{\lambda\mu(R\pi)}$ were decomposed over PW's of total angular momenta J :

$$f^{J}_{\lambda\mu\ (R_\pi)}(W) = \int_0^{\pi} \frac{(2J+1)}{2} f_{\lambda\mu\ (R_\pi)}(W,\theta_\pi,\varphi_\pi=0)\, d^{J}_{\lambda\mu}(\cos(\theta_\pi))\, d(-\cos(\theta_\pi))$$

Full Born term amplitudes implementing subtraction, ISI & FSI :

$$f^{subtr}_{\lambda\mu}(W,\theta_\pi) = \sum_{\substack{j=1/2,\\ 3/2,5/2}} \left(f^{J}_{\lambda\mu}(W) - f^{J}_{\lambda\mu\ R_\pi}(W) \right) d^{J}_{\lambda\mu}(\cos(\theta_\pi)) *$$

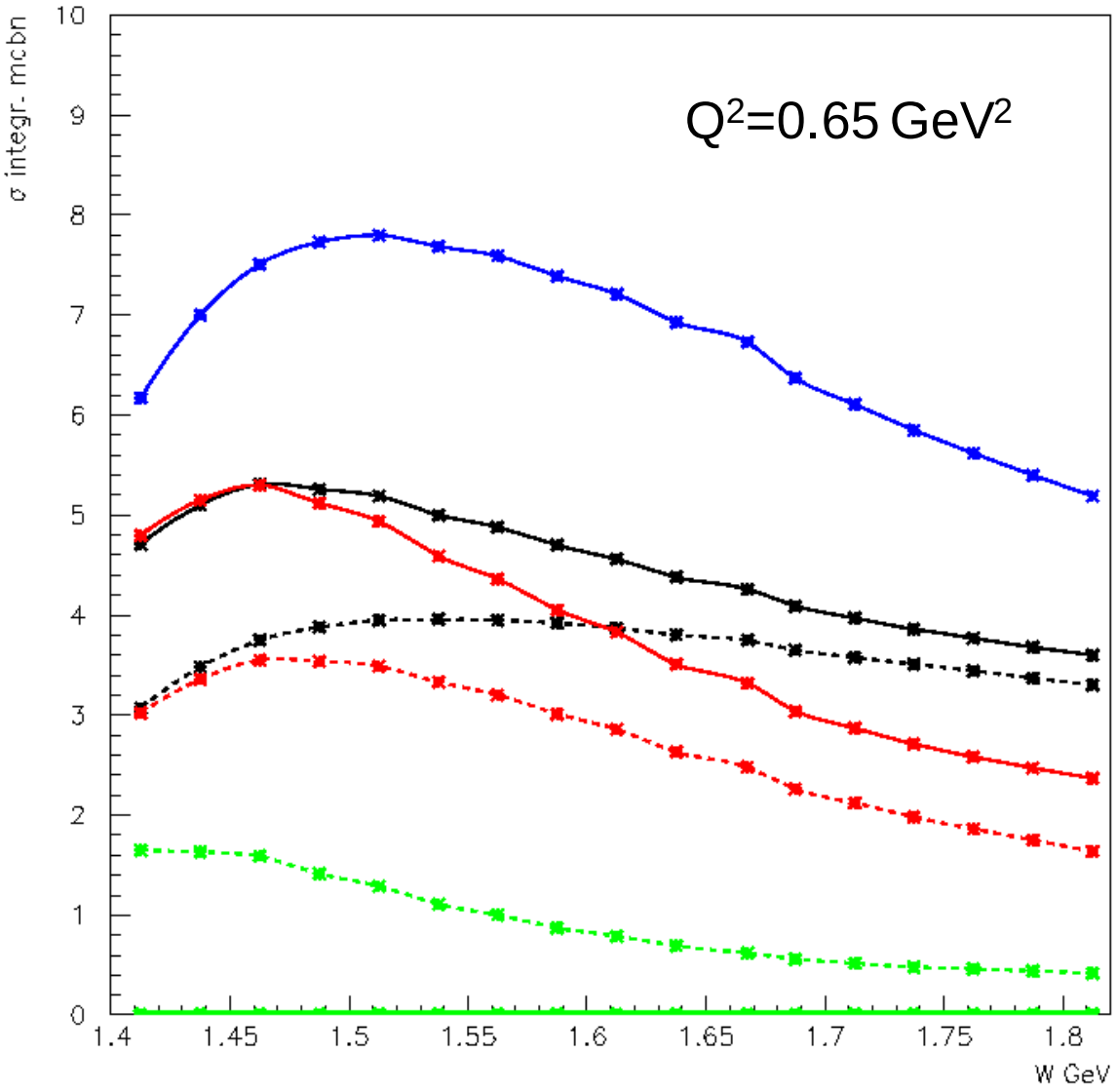
$$* e^{i\lambda\varphi_\pi} * f^{J}_{ISI}\, f^{J}_{FSI} + f^{rest}_{\lambda\mu}(W,\theta_\pi)$$

The contribution to the Born terms from PW with J>5/2 not affected by subtraction and ISI & FSI:

$$f^{rest}_{\lambda\mu}(W,\theta_\pi) = f_{\lambda\mu}(W,\theta_\pi) - \sum_{\substack{j=1/2,\\ 3/2,5/2}} f^{J}_{\lambda\mu}(W)\, d^{J}_{\lambda\mu}(\cos(\theta_\pi))\, e^{i\lambda\varphi_\pi}$$

<u>The prospect:</u> Updated procedure implementing PW truncation consistent with the requirements imposed by unitarity and analyticity on amplitude behavior including unphysical regions (outcome of the recent JPAC studies).

Studies of the subtraction procedure for the Born terms in $\pi^-\Delta^{++}$ channel



Full Born terms:

after subtraction

before subtraction

Born terms, PW's J=1/2,3/2,5/2:

after subtraction

before subtraction

Reggeized π-in flight PW's, J=1/2, 3/2,5/2:

after subtraction

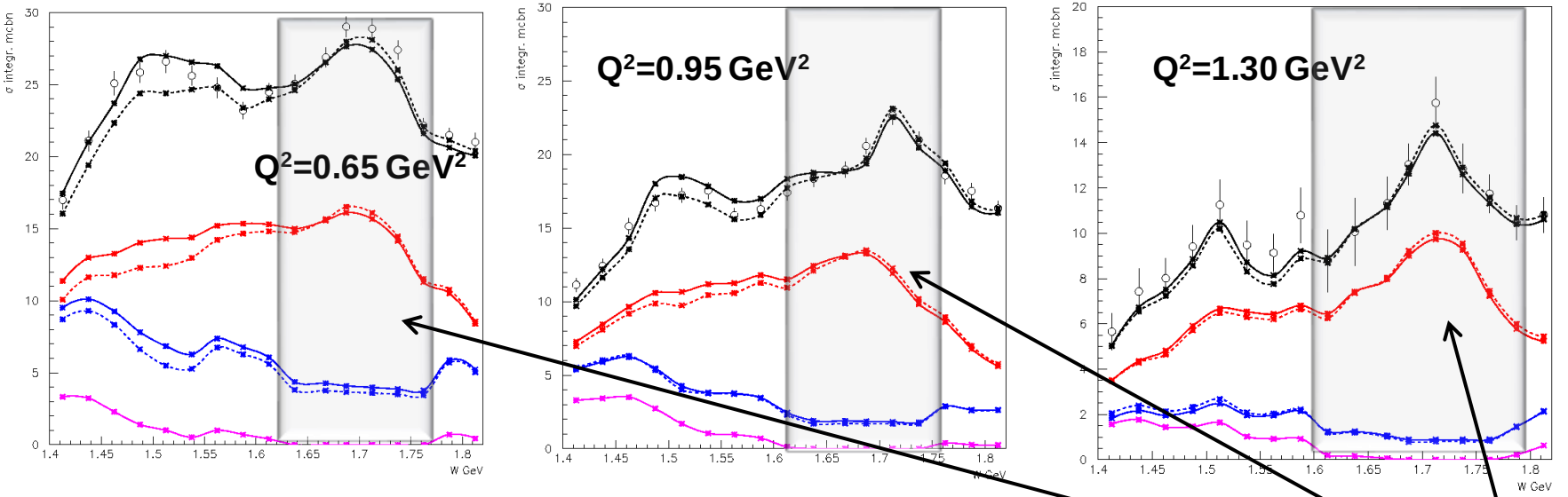
before subtraction

Born terms PW's J>5/2

Subtraction procedure impact decreases with W reflecting growth of the contributions from PW's J>5/2, which are not affected by subtraction.

Impact of subtraction procedure on the data description

Fully integrated $\gamma_v p \to \pi^+\pi^- p$ cross sections



Full $\pi^+\pi^- p$

- after subtraction
- before subtraction

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

- after subtraction
- before subtraction

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

- after subtraction
- before subtraction

extra contact term in $\pi^-\Delta^{++}$

Preferential areas for the N* studies in $\pi^+\pi^-$p electroproduction

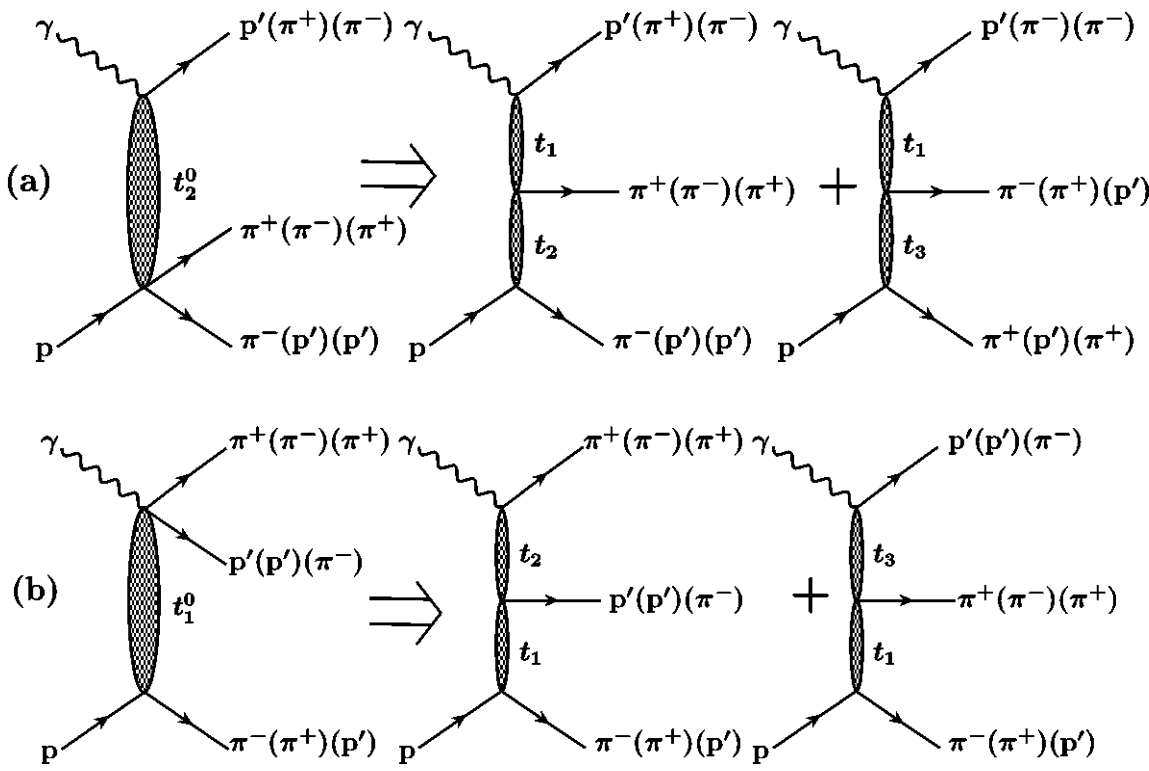
The impact of the subtraction procedure is maximal at W<1.6 GeV and decreases with W and Q^2

Direct 2π Production Mechanisms in the Current Version of the JM Model

$$A(W,Q^2)\varepsilon_\mu(q_\gamma)\bar{U}_{p'}(P_{p'})\gamma^\mu U_p(P_p)*$$
$$e^{b(t_1-t_{1\max})}(P_2P_3)\{\alpha_1(W)e^{b(t_2-t_{2\max})} +$$
$$\alpha_2(W)e^{b(t_3-t_{3\max})}\}$$
$$t_1=(q_\gamma-P_1)^2$$
$$t_2=(P_p-P_3)^2$$
$$t_3=(P_p-P_2)^2$$

$$A(W,Q^2)\varepsilon_\mu(q_\gamma)\bar{U}_{p'}(P_{p'})\gamma^\mu U_p(P_p)*$$
$$e^{b(t_1-t_{1\max})}(P_1P_2)\{\alpha_1(W)e^{b(t_2-t_{2\max})}(t_2-t_{2\max})+$$
$$\alpha_2(W)e^{b(t_3-t_{3\max})}\}$$
$$t_1=(p_P-P_3)^2$$
$$t_2=(q_\gamma-P_1)^2$$
$$t_3=(q_\gamma-P_2)^2$$

The details on amplitude parameterization are in Ref 2, slide #6.



Examples of the CLAS data description achieved employing the direct 2π production mechanisms depicted above can be found in the slide #5

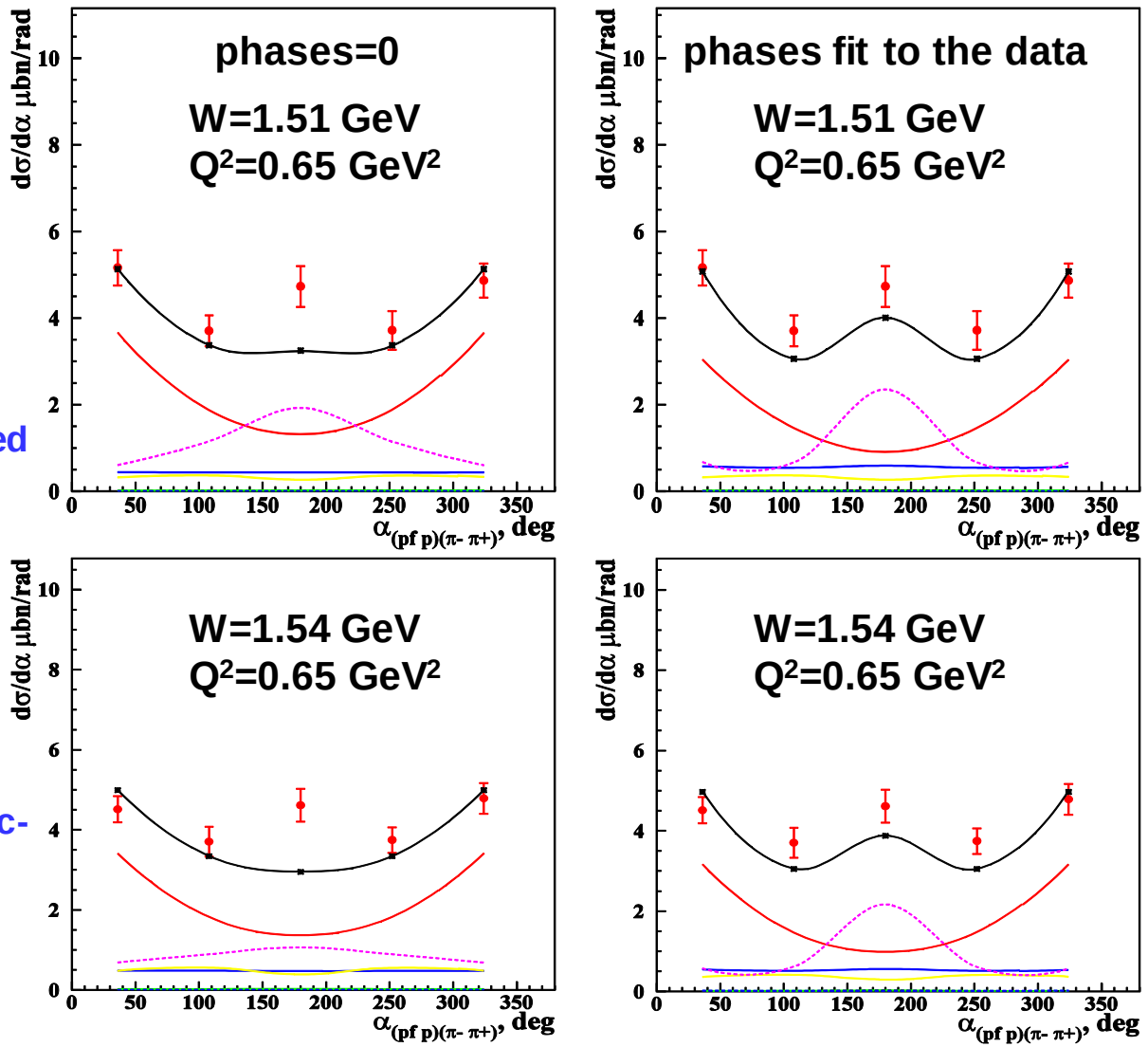
Direct 2π Production Amplitudes: Current Status and Future Developments

phase implementation allowed us to improve description of all differential cross sections, in particular α–angular distributions

Possible future improvements:

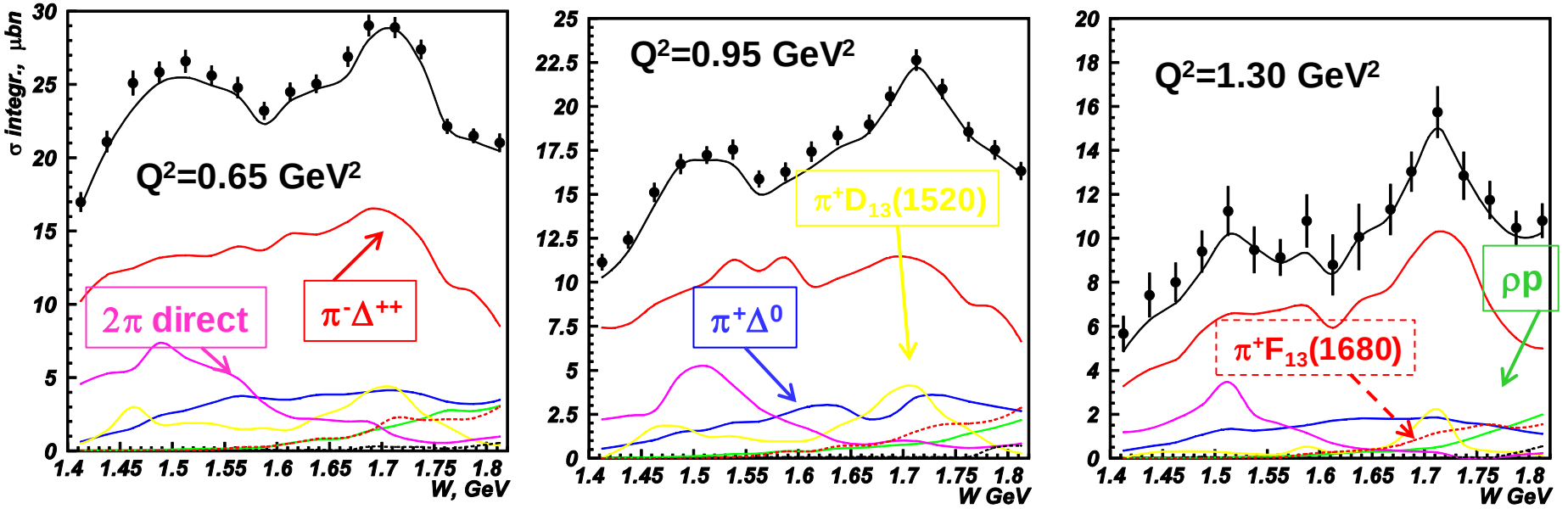
- **phenomenological parameterization can be replaced by the double-Regge limit of B_5 Veneziano model allowing us to decrease the number of fit parameters;**
- **develop the procedure for subtraction of the partial waves which are dual to resonances in s-channel from direct 2π production amplitudes**

Support from JPAC is needed.



the color code is the same as in the slide #5

Charting Meson-Baryon Mechanisms of the JM Model

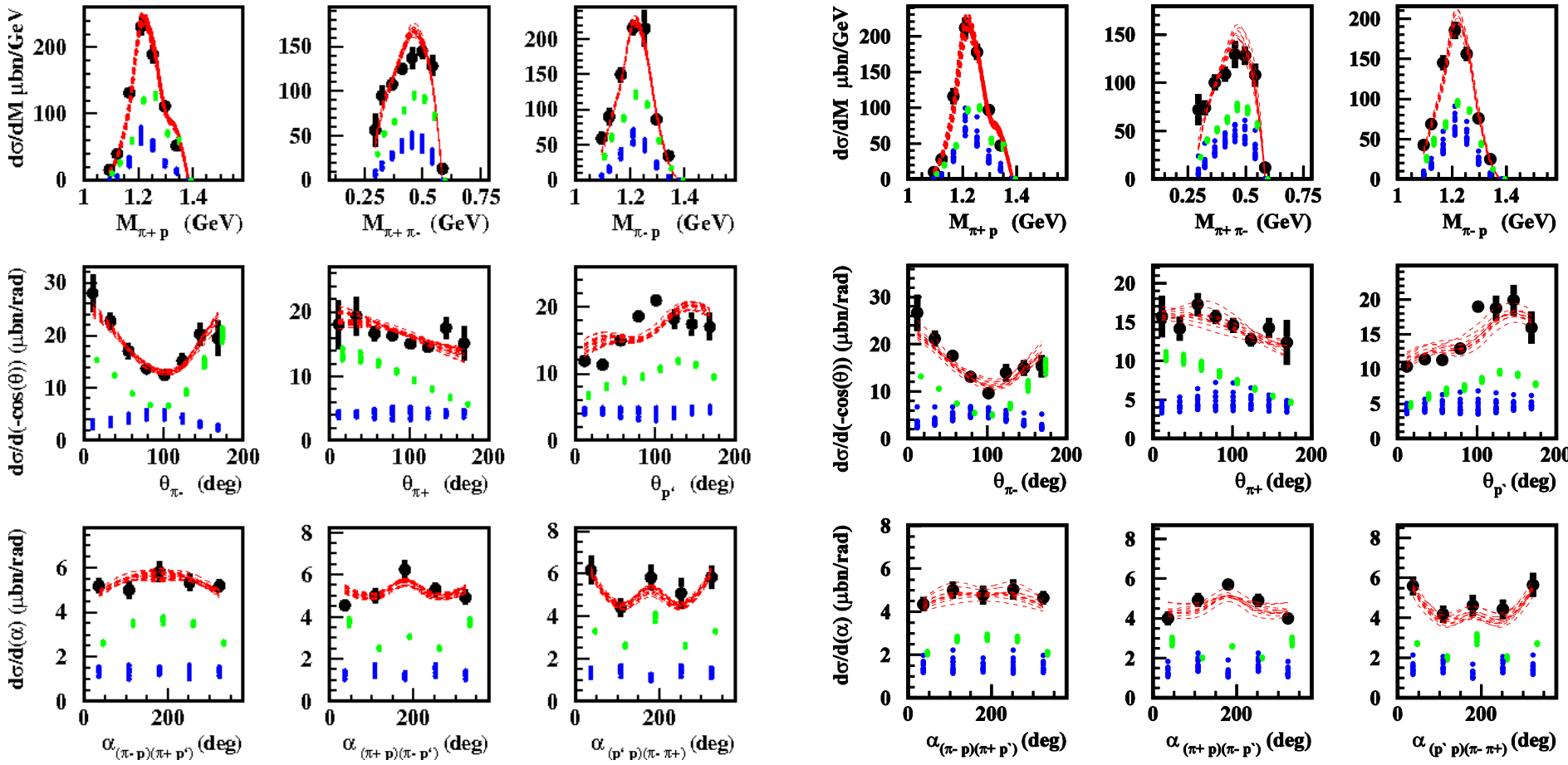


- $\pi^-\Delta^{++}$ meson-baryon channel accounts for the major part of $\pi^+\pi^-p$ electroproduction cross section. Relative resonant contribution to $\pi^-\Delta^{++}$ channel increases with Q^2.
- 2π direct production decreases substantially at W from 1.5 to 1.7 GeV offering an indication for sizable final hadronic interactions between the $\pi^+\pi^-p$ final state and others open meson-baryon channels.
- $\pi\Delta$, ρp-amplitude decomposition over PW's of angular momentum J can be provided from the data fit.
- The request for reaction theory contribution: guidance for the development of analytical continuation of $\pi\Delta$, ρp-amplitudes allowing us to extract resonance electrocouplings from residues at the resonance pole positions.

Resonant /Non-resonant Contributions from the Fit of $\pi^+\pi^-p$ Electroproduction Cross Sections within the JM Model

W=1.51 GeV, Q^2=0.38 GeV^2

W=1.51 GeV, Q^2=0.43 GeV^2



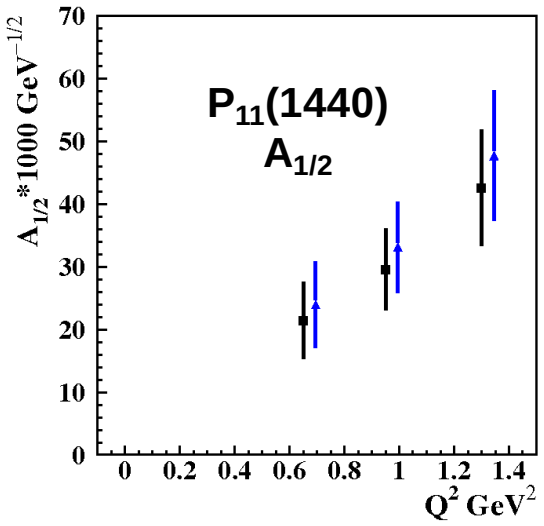
Reliable isolation of the resonant cross sections is achieved

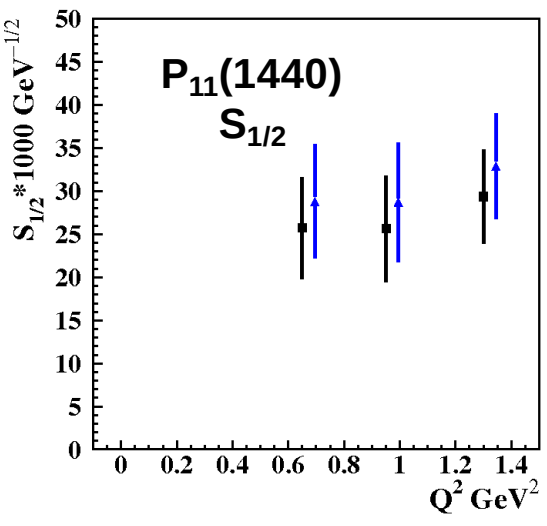
full cross sections within the JM model

resonant part

non-resonant part

Electrocouplings of low-lying resonances. Impact of the subtraction procedure

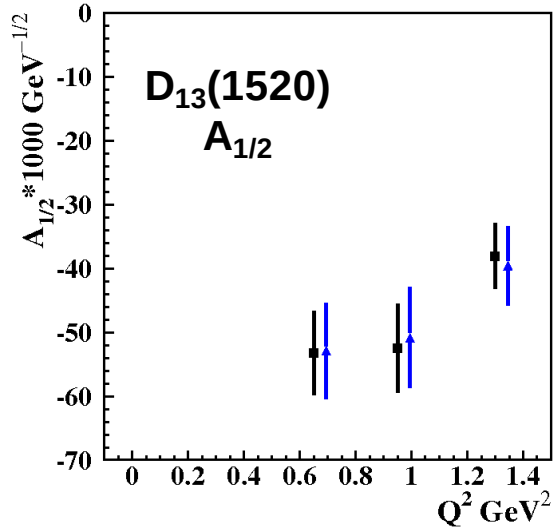


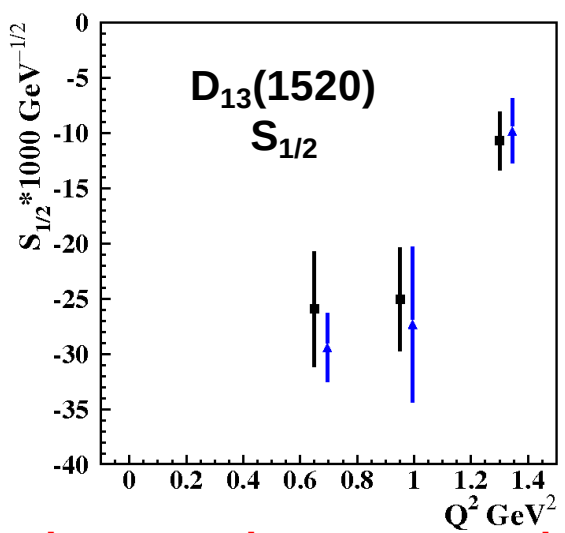


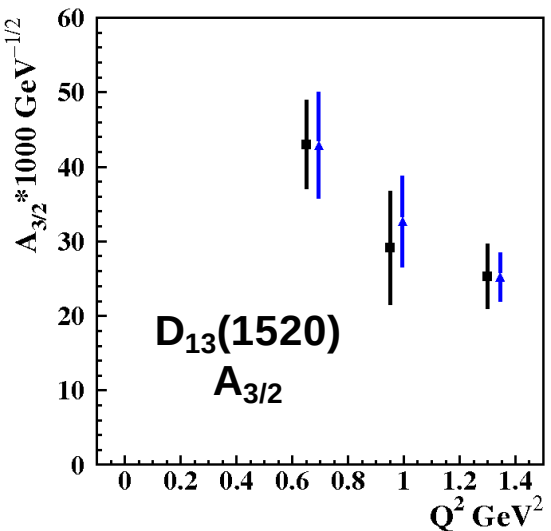
Resonance electrocouplings obtained:

employing subtraction - black

without subtraction - blue





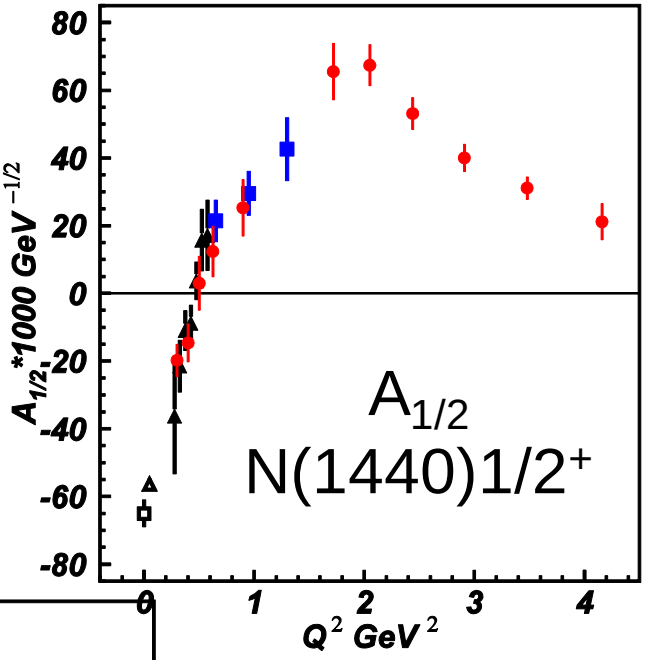


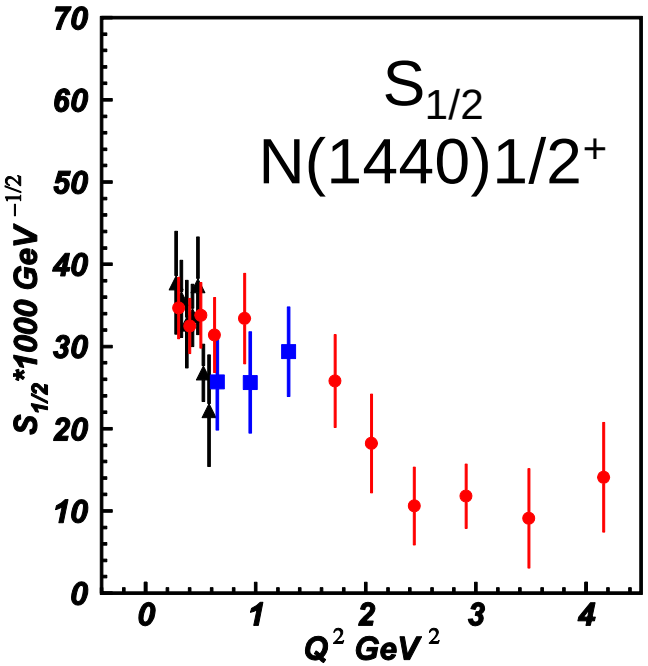
The subtraction procedure does not change γ_vNN* electrocouplings. CLAS data allow credible isolation of resonance contributions within the framework of JM model.

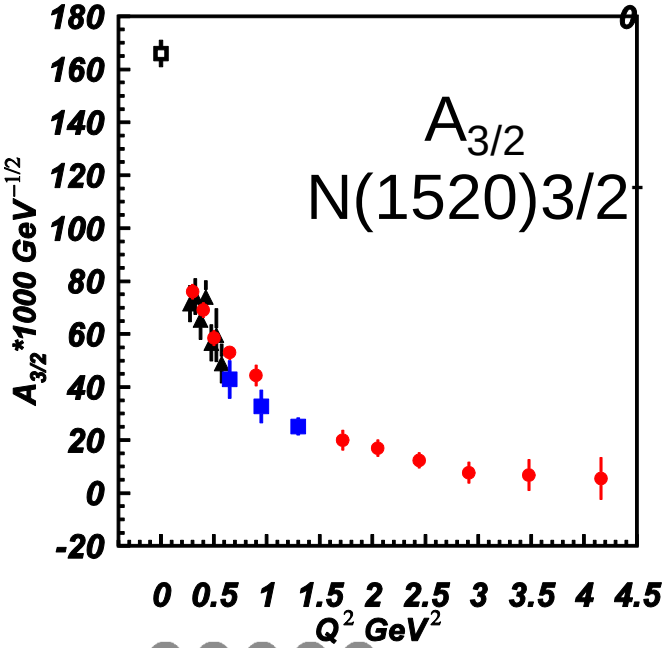
γ_vNN* Electrocouplings From Nπ and $\pi^+\pi^-$p Electroproduction

CLAS data:

- Nπ 2009
- $\pi^+\pi^-$p 2012
- $\pi^+\pi^-$p prelim.







Consistent values of low-lying resonance electrocouplings determined in independent analyses of Nπ and $\pi^+\pi^-$p exclusive channels strongly support:

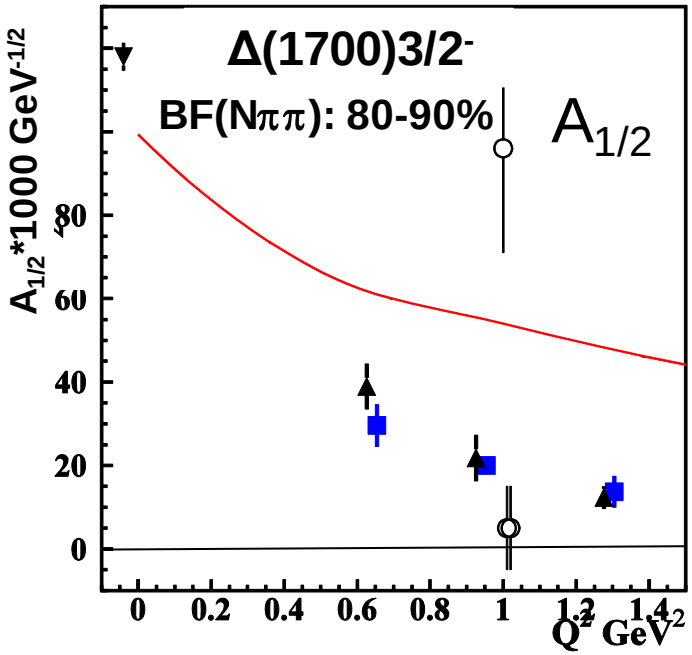
- **reliable electrocoupling extraction;**
- **capabilities of the reaction models to obtain resonance electrocouplings in independent analyses of Nπ and $\pi^+\pi^-$p electroproduction channels.**

Preliminary $\Delta(1700)3/2^-$ electrocouplings from the $\pi^+\pi^-p$ CLAS data

$N\pi$ world
V.D.Burkert, et al., PRC 67, 035204 (2003).

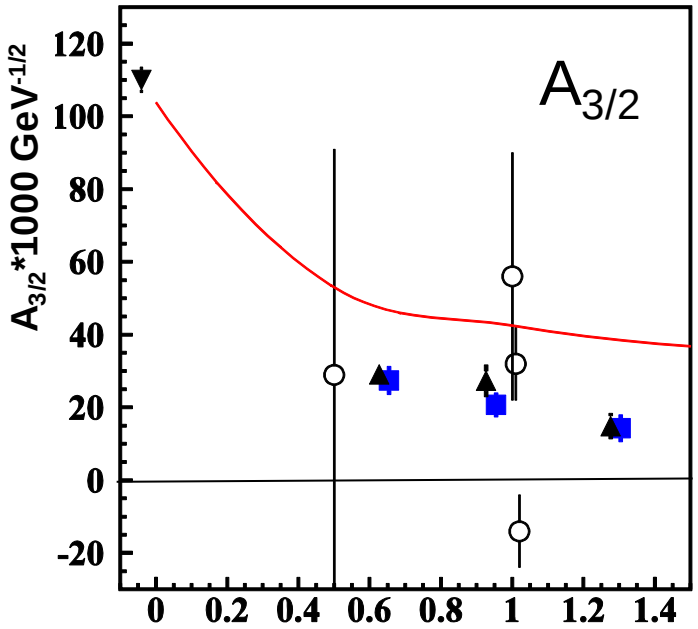
$N\pi\pi$ CLAS preliminary
N* hadr. coupl. are varied
fixed D(1700)3/2$^-$ hadr. couplings

$N\pi$ Q^2=0, CLAS
M.Dugger, et al., PRC 79,065206 (2009).



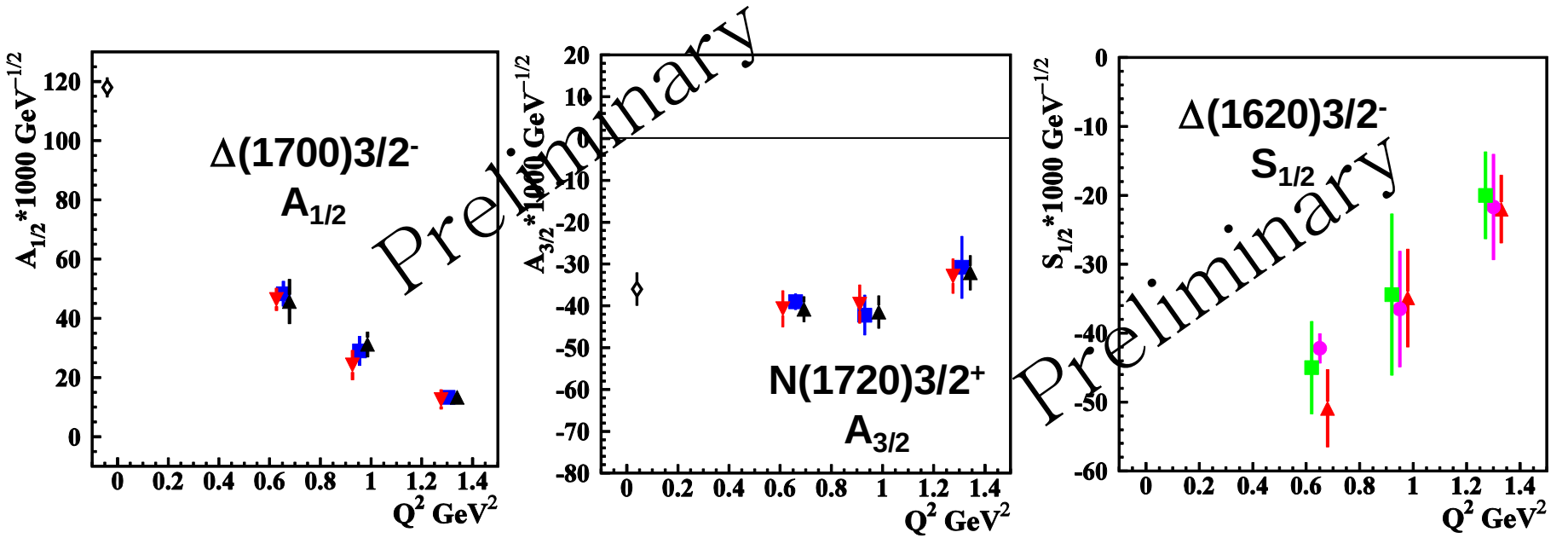
- Studies of $\pi^+\pi^-p$ electroproduction for the first time provided accurate information on $\Delta(1700)3/2^-$ electrocouplings.

- They were determined varying both electrocouplings and $\pi\Delta$, ρp hadronic decay widths of all excited states contributing to the third resonance peak.



Computed from N(1520)3/2$^-$ and N(1535)1/2$^-$ electrocouplings within the SQTM approach:
I.G. Aznauryan and V.D. Burkert, Progr. Nucl. Part. Phys. 67, 1 (2012).

The status and prospects on extraction of high lying N* electrocouplings from the CLAS data



Independent fits in different W-intervals:

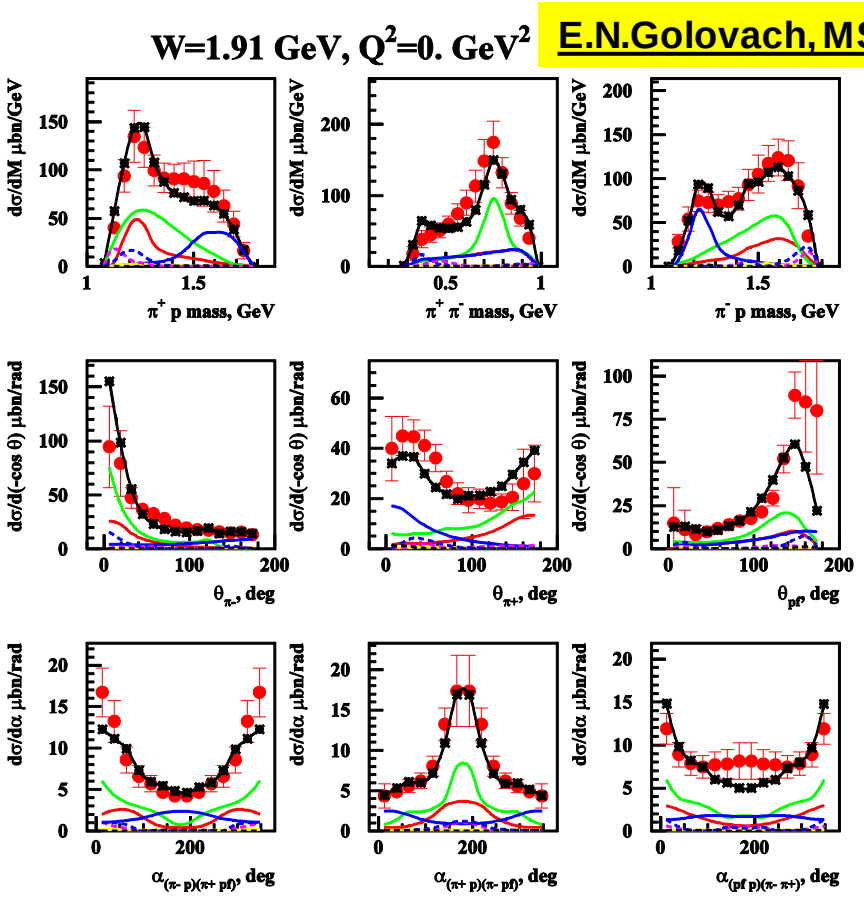
green: 1.46<W<1.56 GeV
magenta: 1.56<W<1.66 GeV
red: 1.61<W<1.71 GeV
blue: 1.66<W<1.76 GeV
black: 1.71<W<1.81 GeV

consistent electrocoupling values offer sound evidence for their reliable extraction.

$\pi^+\pi^-$p electroproduction channel provided first preliminary results on $\Delta(1620)1/2^-$, $N(1650)1/2^-$, $N(1680)5/2^+$, $\Delta(1700)3/2^-$, and $N(1720)3/2^+$ electrocouplings with good accuracy.

Prospect: evaluation of high-mass N* electrocouplings from independent analyses of KY channels. Reaction models capable of extracting resonance electrocouplings from the fit of unpolarized cross sections and polarization asymmetries measured in KY electroproduction are needed!

Preliminary Results on $\pi^+\pi^-$p photoproduction



E.N.Golovach, MSU

Only available data on:

- **9 one-fold differential cross sections;**
- **28 correlated two-fold differential cross sections**

at W from 1.61 GeV to 2.84 GeV

Pronounced differences for three distributions over α-angles in $\pi^+\pi^-$p photo- and electroproduction

Photoproduction data description requires 3-body final state interaction parameterized as :

$$M_i = M_{i_0}\gamma_i\left(1+\beta_i e^{i\alpha_{\pi^-}}\right)$$

$$\gamma_i = \gamma_i\left(s_{\pi^+\pi^-}, s_{\pi^+p}, t_{\gamma\pi^+}, t_{\gamma\pi^-}, t_{pp_f}\right)$$

$$\beta_i = \beta_i(\alpha_{\pi^-})$$

i= $\pi^-\Delta^{++}$, $\pi^+\Delta^0$, ρp, π^+N(1520)3/2$^-$, $\pi^-\Delta^{++}$(1600)3/2$^+$, π^+N(1680)5/2$^+$, σp, 2π direct

The factors γ_i and β_i fwere inferred from the data.

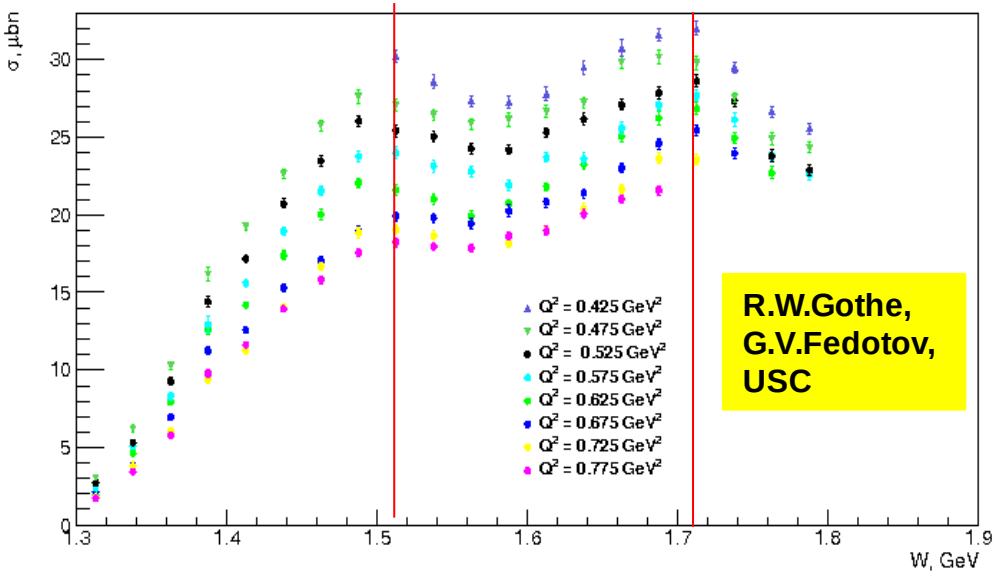
Data error bars: quadratic sum of statistical and systematical

------- σp

legend for other lines is the same as in the slide #5

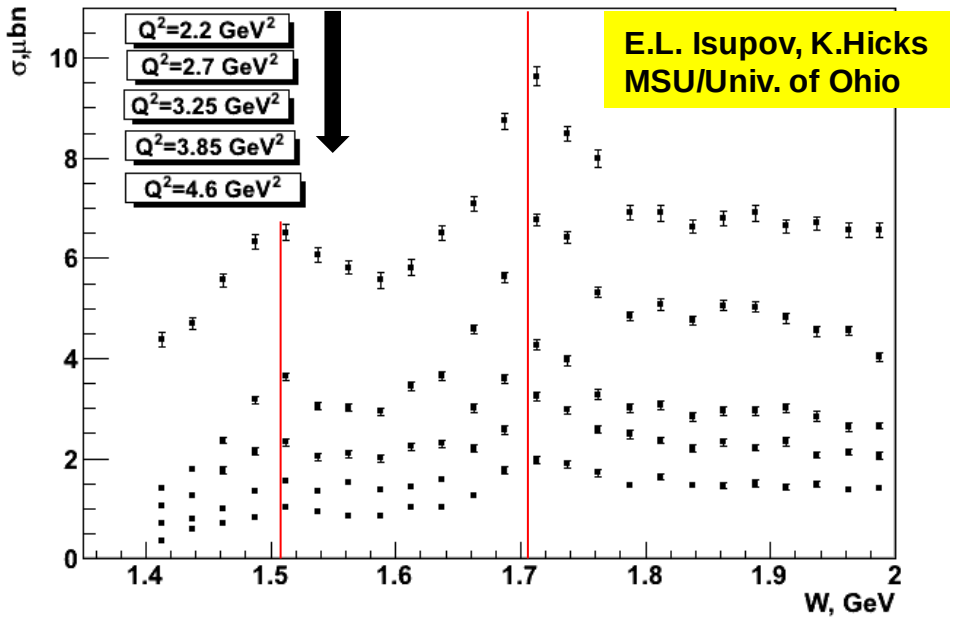
- **Most detailed information on the contributing mechanisms from the experimental data.**
- **Comparison of the results on N* parameters from JM and BoGa models will offer valuable cross checks**
- **Studies of 3/2$^+$(1720) candidate state signal in combined analysis $\pi^+\pi^-$p photo- and electroproduction**
- **Improve knowledge on photo-, $\pi\Delta$ and ρp couplings of high-lying resonances (M_N^*>1.6 GeV)**

Extension of the CLAS $\pi^+\pi^-p$ electroproduction data



Fully integrated $\pi^+\pi^-p$ electroproduction cross sections off protons

- **Nine 1-fold differential cross sections are available In each bin of W and Q^2 shown in the plots.**
- **Resonance structures are clearly seen at W ~1.5 GeV and ~1.7 GeV at $0.4< Q^2< 5.0$ GeV^2 (red lines) .**



Analysis objectives:

- **Extraction of γ_vNN* electrocouplings and $\pi\Delta$, ρp decay widths for most N*'s in mass range up to 2.0 GeV and $0.4< Q^2< 5.0$ GeV^2 within the framework of JM-model.**
- **Exploration of the signals from $3/2^+(1720)$ candidate-state (M.Ripani et al, Phys. Rev. Lett 91, 022002 (2003)) with a goal to achieve decisive conclusion on the state existence and structure.**
- **First results on electrocouplings of high-lying (M_{N^*}>1.6 GeV) orbital nucleon excitations and high-lying parity partners.**

Conclusions

- High quality $\pi^+\pi^-p$ electroproduction data from the CLAS allowed us to develop the data-driven phenomenological model JM for extraction of resonance electrocouplings and $\pi\Delta$, ρp hadronic decay widths from fit of all available observables. Good data description (χ^2/d.p.<2.8) and credible isolation of resonance contribution was achieved at W<1.8 GeV and Q^2<1.5 GeV^2 .

- Consistent electrocoupling values for the transitions to N(1440)1/2$^+$ and N(1520)3/2$^-$ states obtained in independent analyses of $N\pi/N\pi\pi$ exclusive channels demonstrated capabilities of the JM model for reliable extraction of N*-parameters in independent analysis of $\pi^+\pi^-p$ electroproduction data.

- Preliminary results on electrocouplings of for Δ(1620)1/2$^-$, N(1650)1/2$^-$, N(1680)5/2$^+$, Δ(1700)3/2$^-$, and N(1720)3/2$^+$ resonances from $\pi^+\pi p$ electroproduction data at 0.5<Q^2<1.5 GeV^2 have become available for the first time.

- The data on resonance electrocouplings of different N* states in mass range <1.8 GeV open up promising new opportunities for the further development of Dyson-Schwinger Equations of QCD, Lattice QCD and advanced quark models with inputs from QCD field theory approaches for description of these resonance electrocouplings.

Outlook

- **Support from the amplitude analysis experts is needed for the further development of the JM model allowing us:**
  - **a) determine N* parameters at the resonance pole positions employing analytical continuation of $\pi\Delta$ and ρp amplitudes extracted from fit of observables;**
  - **b) explore the possibility to incorporate the double-Regge limit of B_5 Veneziano model for description of direct 2π production mechanisms reducing the number of the fit parameters;**
  - **c) get rid of double counting between resonant contributions in s-channel and dual t-channel processes.**

- **Future analyses of the CLAS $N\pi$, $\pi^+\pi^- p$ and KY photo/electroproduction data will allow electrocouplings to be obtained for all prominent N* states in mass range up to 2.0 GeV at photon virtualities $Q^2<5.0$ GeV^2. Reaction models for extraction of N* parameters from KY electroproduction data are urgently needed.**

Back up

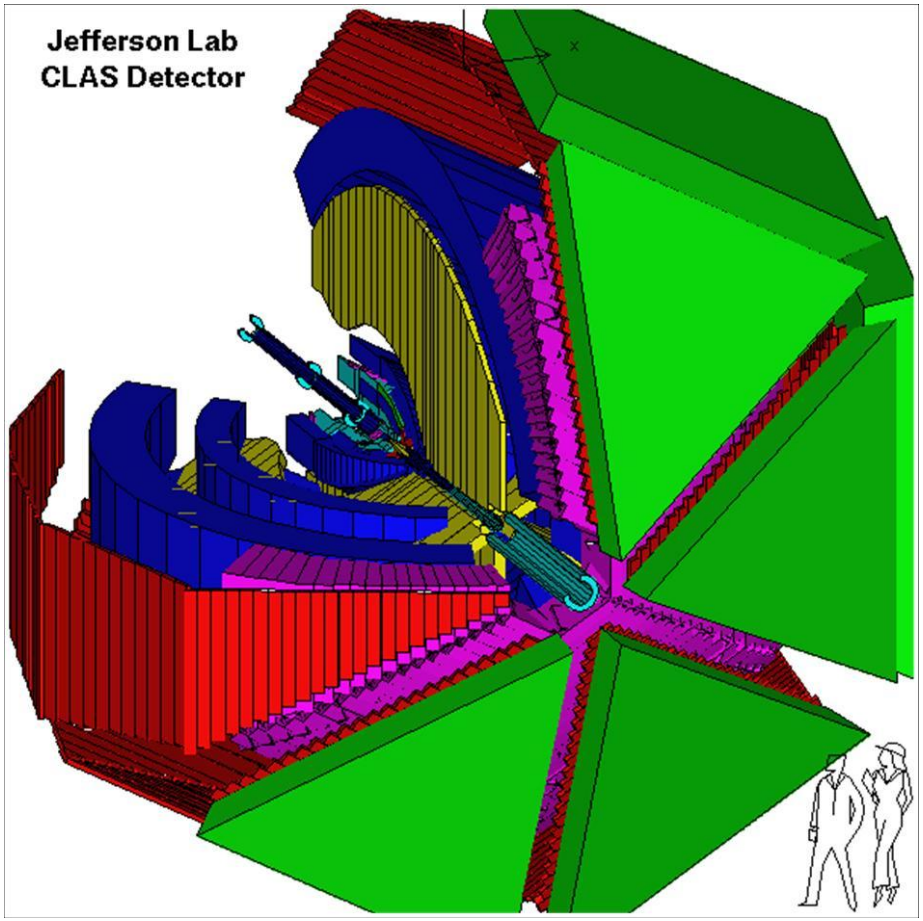
CEBAF Large Acceptance Spectrometer

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/$\pi\iota$ separation, 216 PMTs

Electromagnetic calorimeters
Lead/scintillator, 1296 PMTs

The unique combination of the CEBAF continuous electron beam and the CLAS detector makes Hall-B@JLAB the only facility operational worldwide, that is capable of measuring unpolarized cross sections and polarization asymmetries of most exclusive meson electroproduction channels with substantial contributions at W<3.0 GeV and Q^2<5.0 GeV^2.

Summary of the CLAS Data on Exclusive Meson Electroproduction off Protons in N* Excitation Region

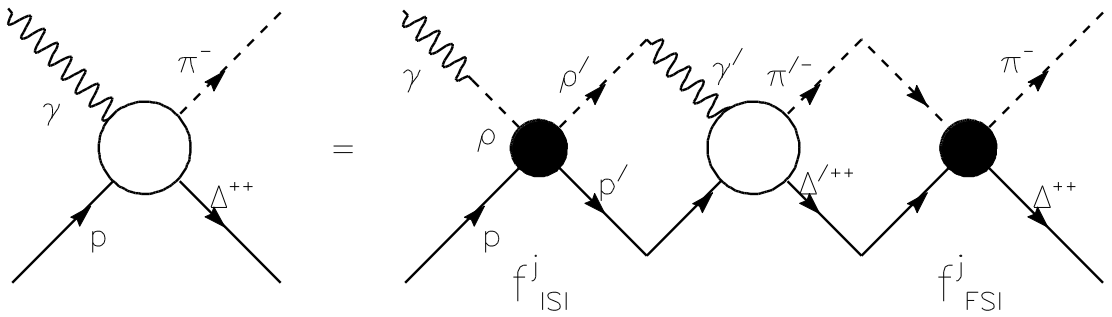
Hadronic final state	Covered W-range, GeV	Covered Q^2-range, GeV^2	Measured observables
π^+n	1.1-1.40 1.1-1.55 1.1-1.7	0.15-0.40 0.3-0.6 1.7-4.2	$d\sigma/d\Omega$ $d\sigma/d\Omega$ $d\sigma/d\Omega$, A_b
π^0p	1.1-1.40 1.1-1.7 1.1-1.7	0.15-0.40 0.4-0.7 0.75-6.0	$d\sigma/d\Omega$ $d\sigma/d\Omega$, A_b,A_t,A_{bt} $d\sigma/d\Omega$
ηp	1.5-2.0	0.2-4.0	$d\sigma/d\Omega$
$K^+\Lambda$	1.65-2.35 1.65-2.35	0.65-2.55 1.4-2.6	$d\sigma/d\Omega$ P’
$K^+\Sigma^0$	1.7-2.1 1.8-2.5 1.7-2.6	0.5-2.55 1.5-3.50 1.8-3.50	$d\sigma/d\Omega$ P’ $d\sigma/d\Omega$
$\pi^+\pi^-p$	1.3-1.6 1.4-2.1	0.2-0.6 0.5-1.5	Nine 1-fold differential cross sections

- $d\sigma/d\Omega$–CM angular distributions
- A_b,A_t,A_{bt}-longitudinal beam, target, and beam-target asymmetries
- P’ –recoil polarization of strange baryon

The data are available in the CLAS Physics Data Base:

http://depni.sinp.msu.ru/cgi-bin/jlab/db.cgi

Accounting for the ISI & FSI in πΔ Channels



Absorptive ansatz proposed in K.Gottfried, J.D.Jackson, Nuovo Cimento 34, 736 (1964) and developed for the use in the JM model in M.Ripani et al., Nucl Phys. A672, 220 (2000).

Non-resonant parts of πΔ amplitudes computed from tree diagrams $T^{J\ tree}_{\lambda\mu}$ are multiplied by the absorptive factors in the initial an final states f^J_{ISI} , f^J_{FSI} :

$$T^{J\ full}_{\lambda\mu} = f^J_{ISI}\, T^{J\ tree}_{\lambda\mu}\, f^J_{FSI}$$

$$\lambda = \lambda_\gamma - \lambda_p$$

$$\mu = -\lambda_\Delta$$

$$f^J_{ISI} = \left\langle \lambda_\rho \lambda_p \left| S^J \right| \lambda_\rho \lambda_p \right\rangle^{1/2}$$

$$f^J_{FSI} = \left\langle \pi \lambda_\Delta \left| S^J \right| \pi \lambda_\Delta \right\rangle^{1/2}$$

$$S = 1 + 2iT$$

Possible improvement: absorptive ansatz can be replaced by the results of coupled channel analyses on the ratio R: πΔ (photo) electroproduction amplitudes accounting for FSI $T^{J\ full}_{\pi\Delta}$ over their values computed from tree diagrams $T^{J\ tree}_{\pi\Delta}$:

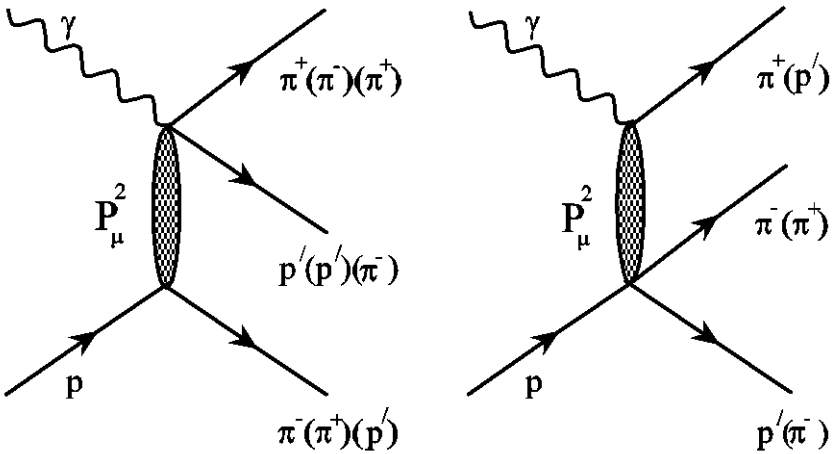
$$R = T^{J\ full}_{\lambda\mu} \Big/ T^{J\ tree}_{\lambda\mu} \qquad T^{J\ full}_{\lambda\mu} = T^{J\ tree}_{\lambda\mu} R$$

Parameterization of Direct 2π Production Amplitudes Based on the CLAS Data Description.

data descriptions achieved with 2π direct production mechanisms described as:

..... phase space

——— exchange mechaniss:

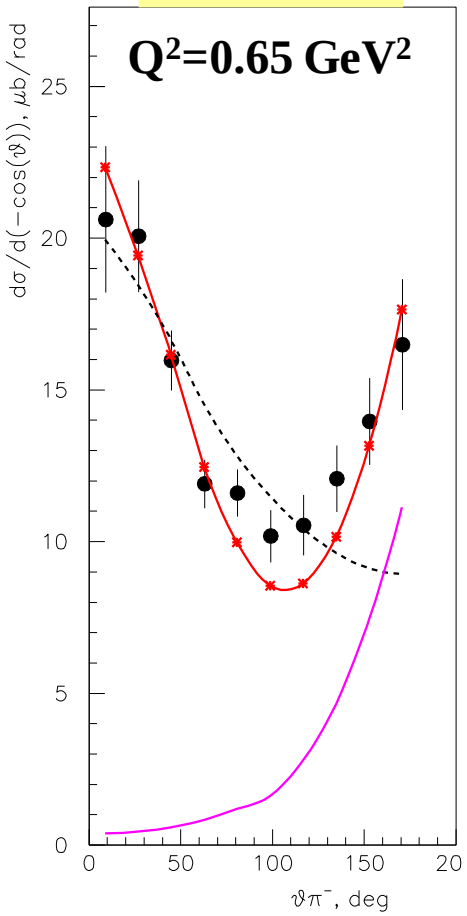


$$M_d = A(W,Q^2)\varepsilon_\mu^\gamma \overline{U}_{p'}\gamma_\mu U_p *$$

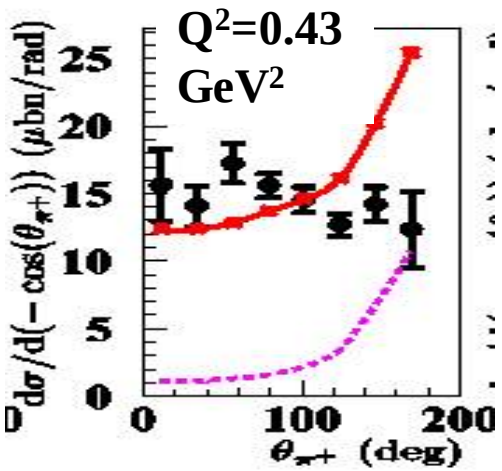
$$\frac{1}{W^4} e^{b(P_\mu^2 - P_{\mu\min}^2)}(P_1P_2)$$

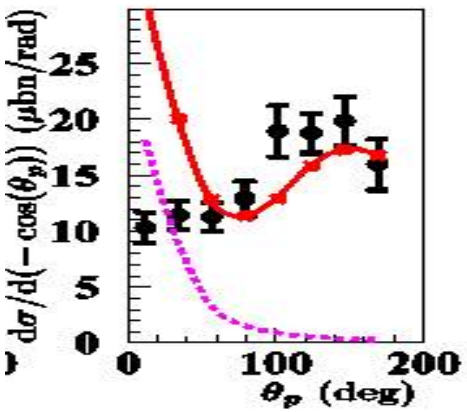
Further improvements in description of direct 2π production mechanisms were implemented.

W=1.49 GeV



W=1.51 GeV





——— Contributions of 2π direct production described by exchange processes

Signals from N* states in the CLAS KY electroproduction data

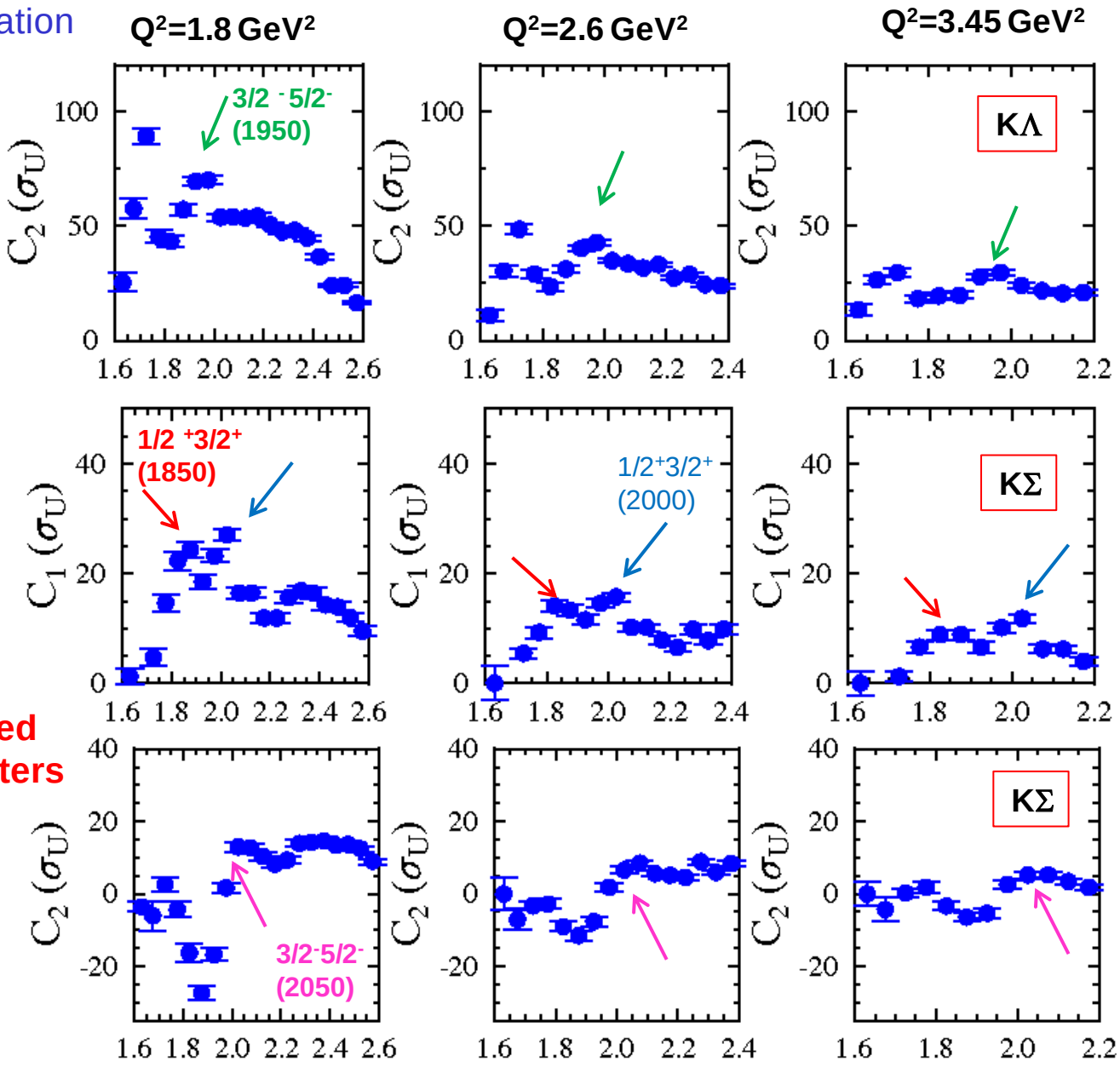
D.Carman, private communication

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

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

the structures in W-dependencies of C_l – moments at the same W-values in all Q^2-bins are consistent with the contributions from resonances of spin-parities listed in the plots

reaction model(s) are needed for extraction of N* parameters from KY electroproduction



CLAS12

CLAS12 supports a broad program in hadronic physics.

Plans to study excited baryons and mesons:

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