Nucleon Resonance Studies with CLAS12

PR12-06-116 at JLab PAC 30, August 21-25, 2006

Excerpt of the PAC30 comments

Measurement and Feasibility: The resonances to be identified in the relevant partial waves have widths greater than 120-150 MeV. For these the expected CLAS12 energy resolution of 60 MeV looks adequate. While the ultimate goal is to extract N* photocouplings from the data, the experiment could produce absolute cross sections that may be analyzed by independent theoretical groups.

Issues: Whether the Q^2 dependence of the photocouplings of the observed excited baryons really reveals an undressing of the constituent quarks appears to be highly model dependent at present. This situation may well develop over the next decade aided by lattice calculations, for example.

The ongoing work of the collaboration in addressing the nature of the N*s is appreciated. They are urged to consider developing a more adequate proposal for the 12GeV upgrade in which the interpretation issues of what one learns from the Q^2 dependence of the resonance photocouplings are more sharply addressed.

Workshop on “Electromagnetic N-N* Transition Form Factors,” Oct. 2008, 42 Participants

White Paper “Theory Support for the Excited Baryon Program at the JLab 12 GeV Upgrade”

Nucleon Resonance Studies with CLAS12

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JLab PAC 34, January 26-30, 2009

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JLab PAC 34, January 26-30, 2009

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Physics Goals

- Measure differential cross sections and polarization observables in single and double pseudoscalar meson production: π^+n, π^0p, ηp and $\pi^+\pi^-p$ over the full polar and azimuthal angle range. ✓

- Determine electrocouplings of prominent excited nucleon states (N^*, Δ^*) in the fully unexplored Q^2 range of 5-12 GeV^2 and extend considerably the data base on fundamental form factors of nucleon states, which is needed to explore the confinement in the baryon sector.

"ultimate goal"

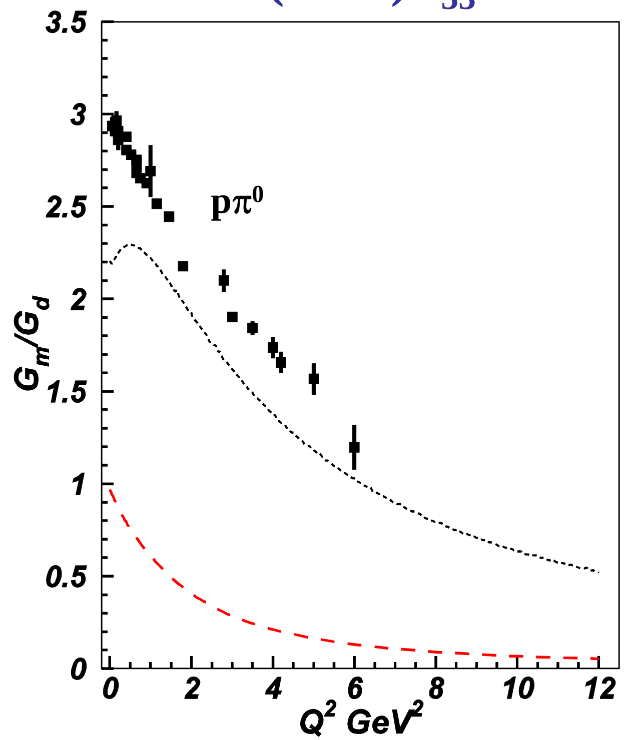
- These data for the first time will allow us to:
  - Study the structure of the nucleon spectrum in the domain where dressed quarks are the major active degree of freedom.
  - Explore the formation of excited nucleon states in interactions of dressed quarks and their emergence from QCD.

"address more sharply"

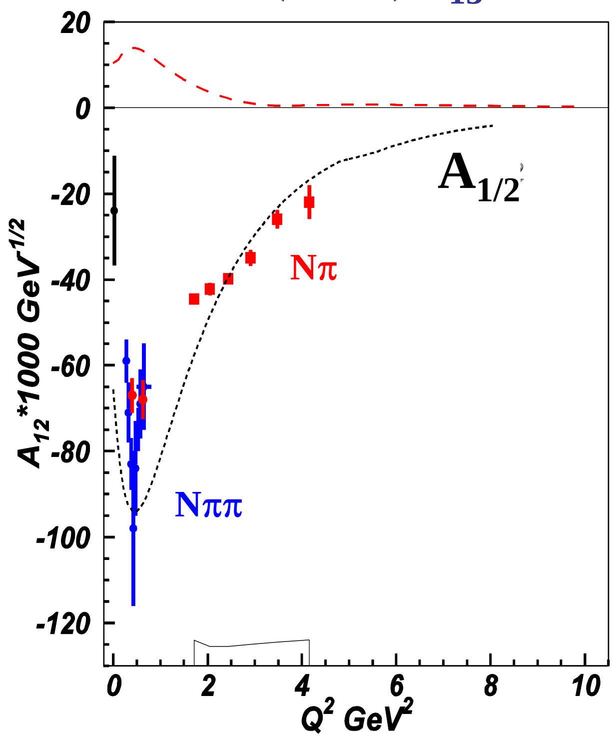
Progress in Experiment and Phenomenology

Recent experimental and phenomenological efforts show that meson-baryon contributions to resonance formations drop faster with Q^2 than the contributions from dressed quarks.

$\Delta(1232)P_{33}$



$N(1520)D_{13}$

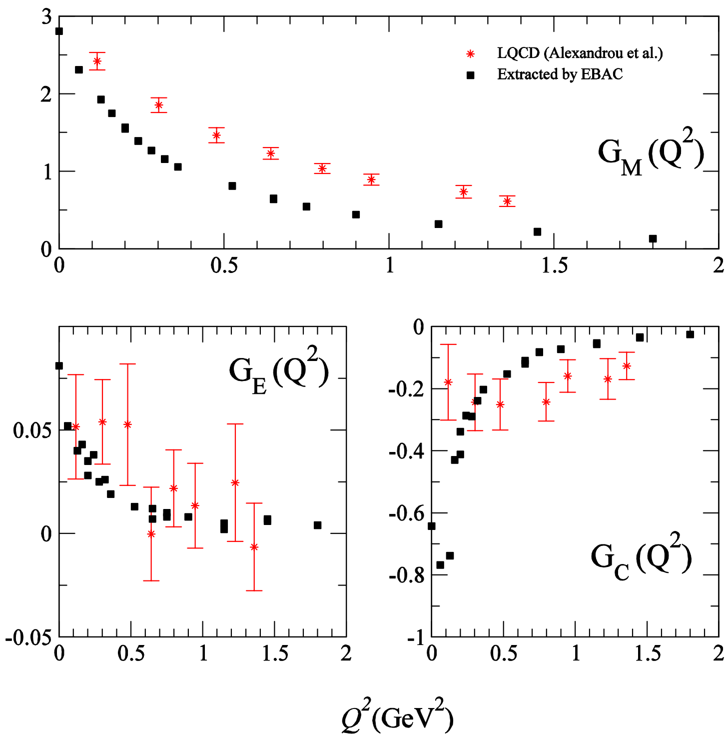


.... Dressed quarks (B. Julia-Diaz *et al.* and M. Giannini *et al.*)

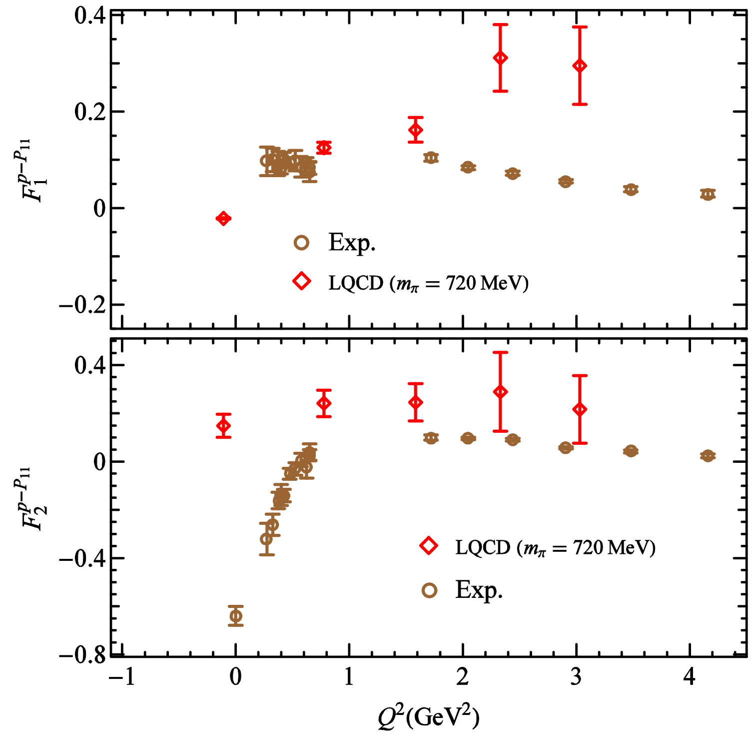
- - - - Meson-baryon cloud (EBAC)

Resonance Electrocouplings in Lattice QCD

$\Delta(1232)P_{33}$



$N(1440)P_{11}$

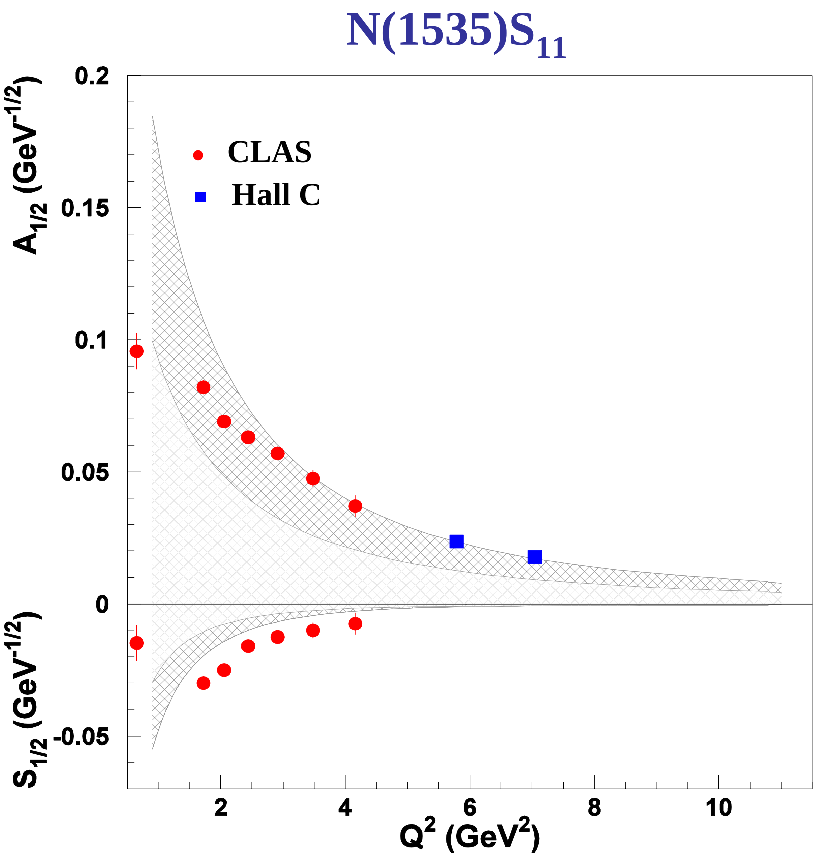


LQCD calculations of the $\Delta(1232)P_{33}$ and $N(1440)P_{11}$ transitions have been carried out with large π-masses.

By the time of the upgrade LQCD calculations of N* electrocouplings will be extended to $Q^2 = 10$ GeV^2 near the physical π-mass as part of the commitment of the JLab LQCD and EBAC groups in support of this proposal.

see White Paper Sec. II and VIII

LQCD & Light Cone Sum Rule (LCSR) Approach



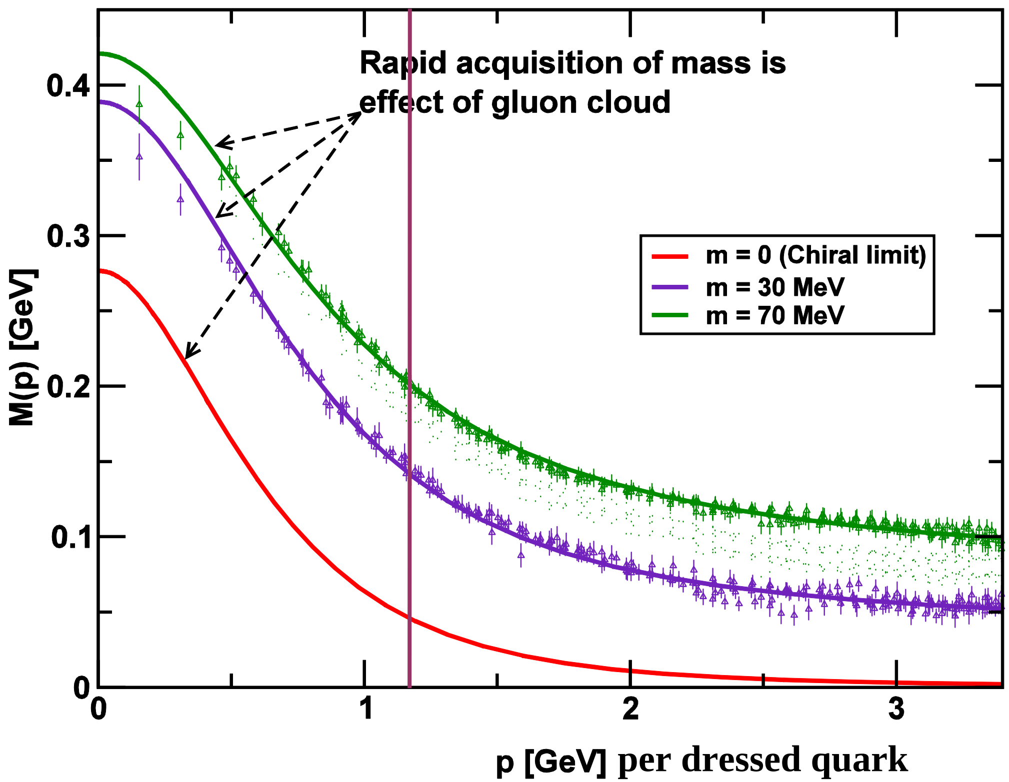
LQCD is used to determine the moments of N* distribution amplitudes (DA) and the N* electrocouplings are determined from the respective DAs within the LCSR framework.

Calculations of N(1535)S_{11} electrocouplings at Q^2 up to 12 GeV^2 are already available and shown by shadowed bands on the plot.

By the time of the upgrade electrocouplings of others N*s will be evaluated. These studies are part of the commitment of the U. Regensburg group in support of this proposal.

see White Paper Sec. V

Dynamical Mass of Light Dressed Quarks



DSE and LQCD predict the dynamical generation of the momentum dependent dressed quark mass that comes from the gluon dressing of current quark propagator.

These dynamical contributions account for more than 98% of the dressed light quark mass.

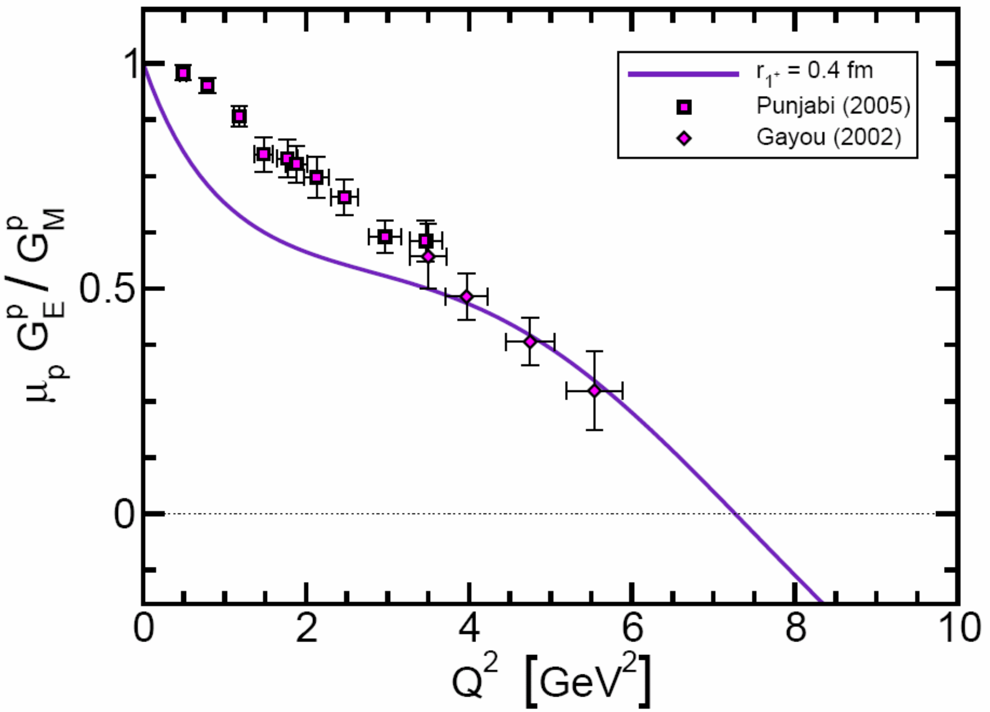
DSE: lines and LQCD: triangles

$Q^2 = 12\ GeV^2 = (p \text{ times number of quarks})^2 = 12\ GeV^2 \rightarrow p = 1.15\ GeV$

The data on N* electrocouplings at $5<Q^2<12\ GeV^2$ will allow us to chart the momentum evolution of dressed quark mass, and in particular, to explore the transition from dressed to almost bare current quarks as shown above.

Dyson-Schwinger Equation (DSE) Approach

DSE provides an avenue to relate N* electrocouplings at high Q^2 to QCD and to test the theory's capability to describe N* formations based on QCD.



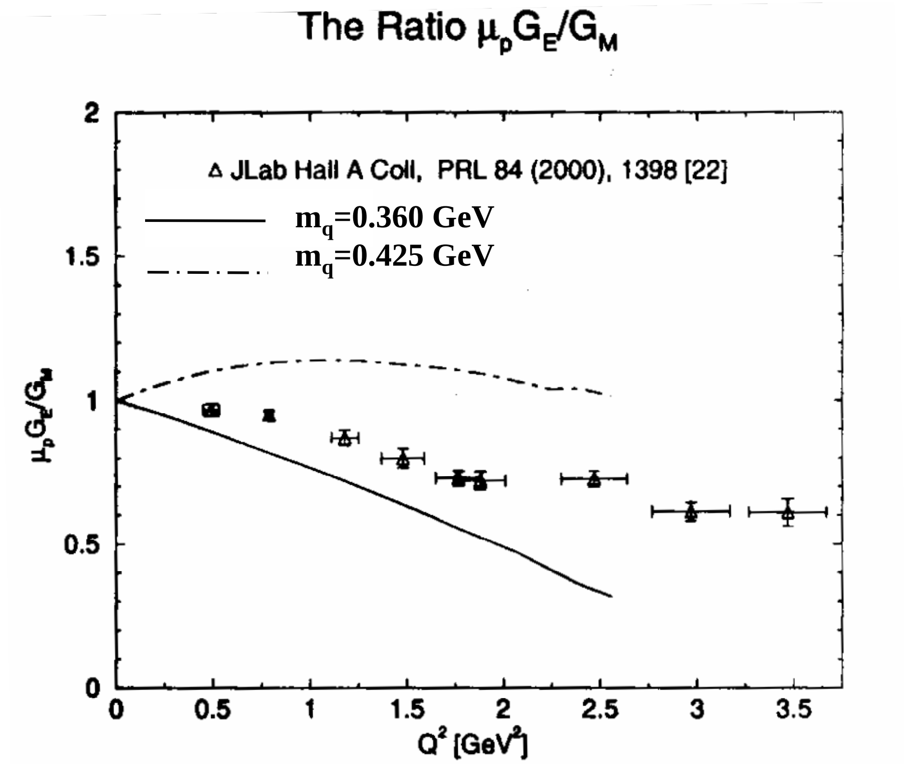
DSE approaches provide a link between dressed quark propagators, form factors, scattering amplitudes, and QCD.

N* electrocouplings can be determined by applying Bethe-Salpeter /Fadeev equations to 3 dressed quarks while the properties and interactions are derived from QCD.

By the time of the upgrade DSE electrocouplings of several excited nucleon states will be available as part of the commitment of the Argonne NL and the University of Washington.

see White Paper Sec. III

Electrocoupling Sensitivity to Light Dressed Quark Mass



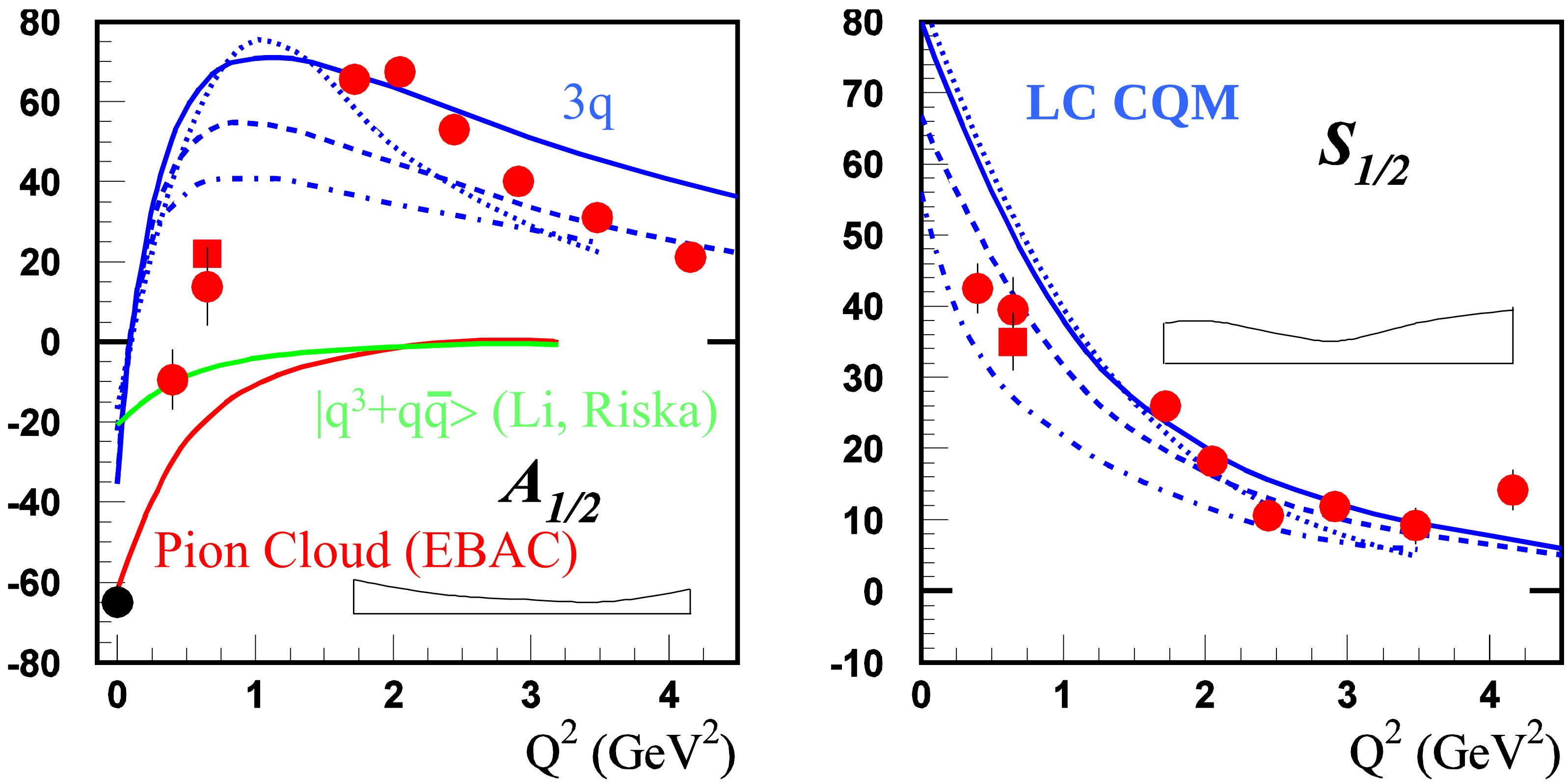
N* electrocouplings are sensitive to the momentum dependence of the dressed quark mass. This affects the

- ➢ dressed quark propagator and
- ➢ qq correlations.

NJL calculations of elastic form factors with two different values of non-running dressed quark mass as shown above demonstrate the sensitivity to the dressed quark mass. Detailed studies of the manifestation of the dressed quark mass momentum dependence in Q^2-evolution of the N* electrocouplings will be carried out by the Argonne NL and U. of Washington groups by 2014.

see White Paper Sec. III

Constituent Quark Models (CQM)



N(1440)P_{11}: ● PDG value ● Nπ ■ Nπ, Nππ combined analysis

Relativistic CQM are **currently** the only available tool to study the electrocouplings for the majority of excited proton states.

This activity represent part of the commitment of the Yerevan Physics Institute, the University of Genova, INFN-Genova, and the Beijing IHEP groups to refine the model further, e.g., by including $q\bar{q}$ components.

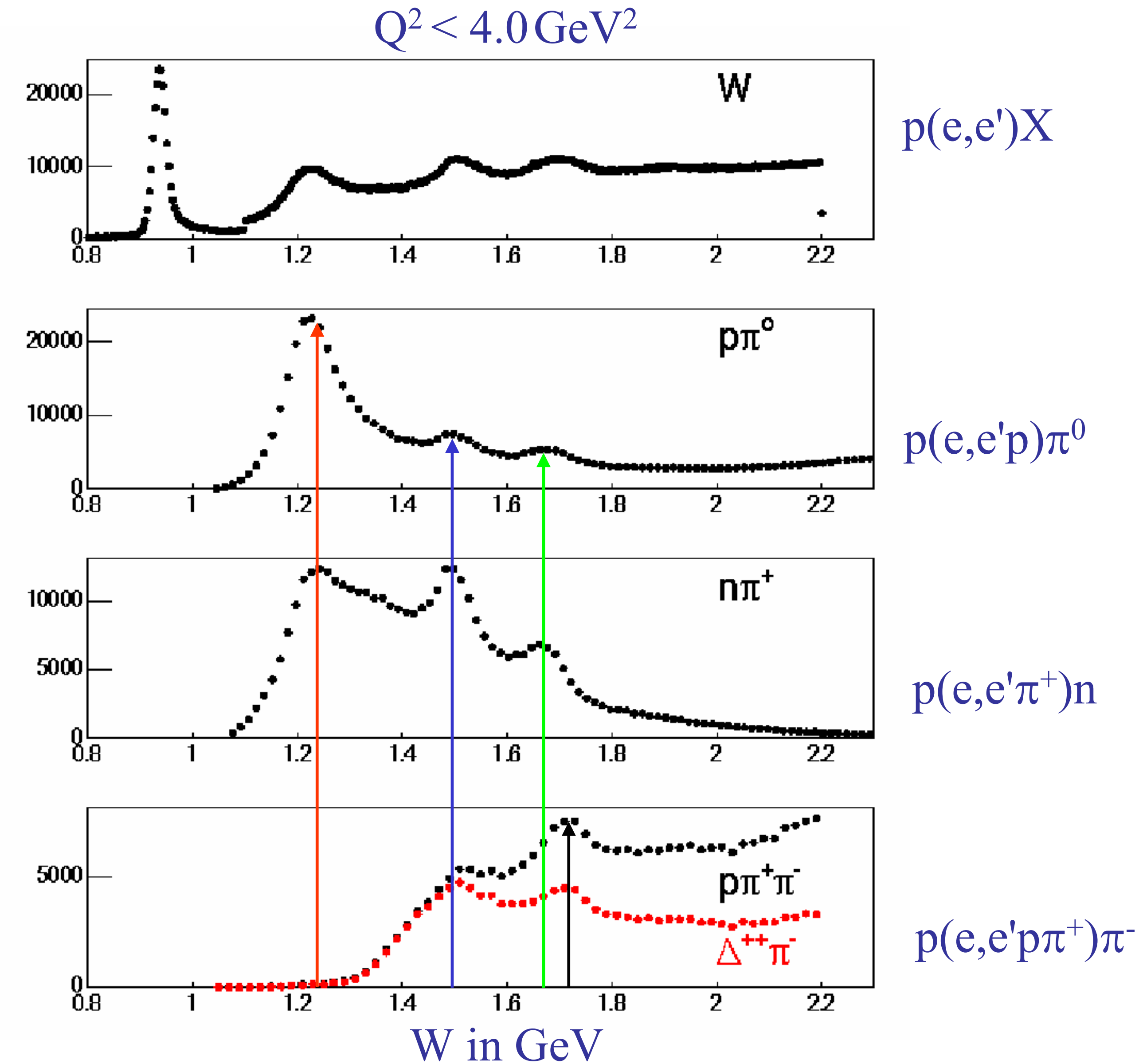
see White Paper Sec. VI

Nucleon Resonances in Nπ and Nππ Electroproduction

- Nππ channel is sensitive to N*s heavier than 1.4 GeV

- Provides information that is complementary to the Nπ channel

- Many higher-lying N*s decay preferentially into Nππ final states



Phenomenological Analyses

- Unitary Isobar Model (UIM) approach in single pseudoscalar meson production
- Fixed-*t* Dispersion Relations (DR)
- Isobar Model for $N\pi\pi$ final state (JM)

see White Paper Sec. VII

- Coupled-Channel Approach (EBAC)

see White Paper Sec. VIII

Phenomenological Analyses in Single Meson Production

Unitary Isobar Model (UIM)

Nonresonant amplitudes: gauge invariant Born terms consisting of *t*-channel exchanges and *s*- / *u*-channel nucleon terms, reggeized at high W.
πN rescattering processes in the final state are taken into account in a K-matrix approximation.

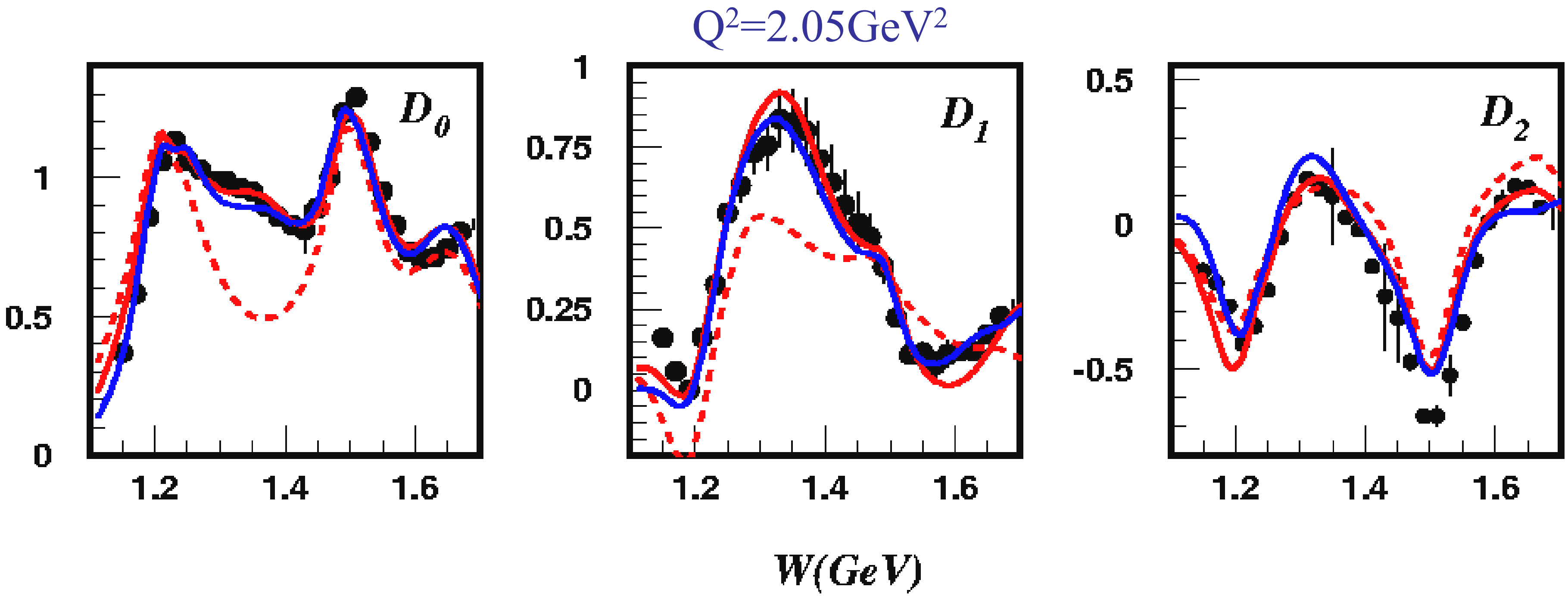
Fixed-*t* Dispersion Relations (DR)

Relates the real and the imaginary parts of the six invariant amplitudes in a model-independent way. The imaginary parts are dominated by resonance contributions.

see White Paper Sec. VII

Legendre Moments of Unpolarized Structure Functions

K. Park *et al.* (CLAS), Phys. Rev. C77, 015208 (2008)



$$\sigma_T + \epsilon\sigma_L = \sum_{l=0}^{n} D_l^{T+L} P_l(\cos\theta_\pi^*)$$

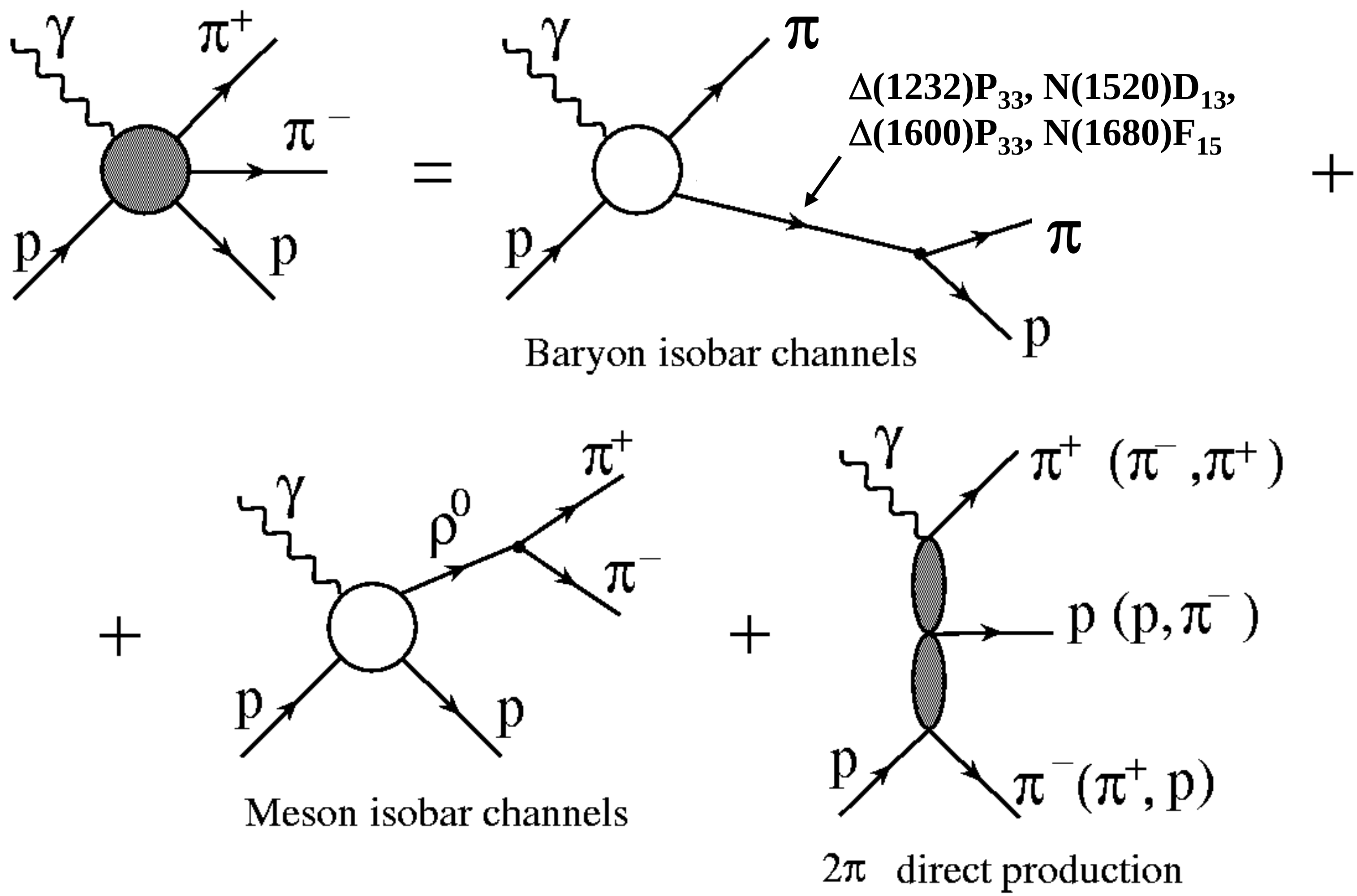
I. Aznauryan —— DR fit

I. Aznauryan - - - DR fit w/o P_{11}

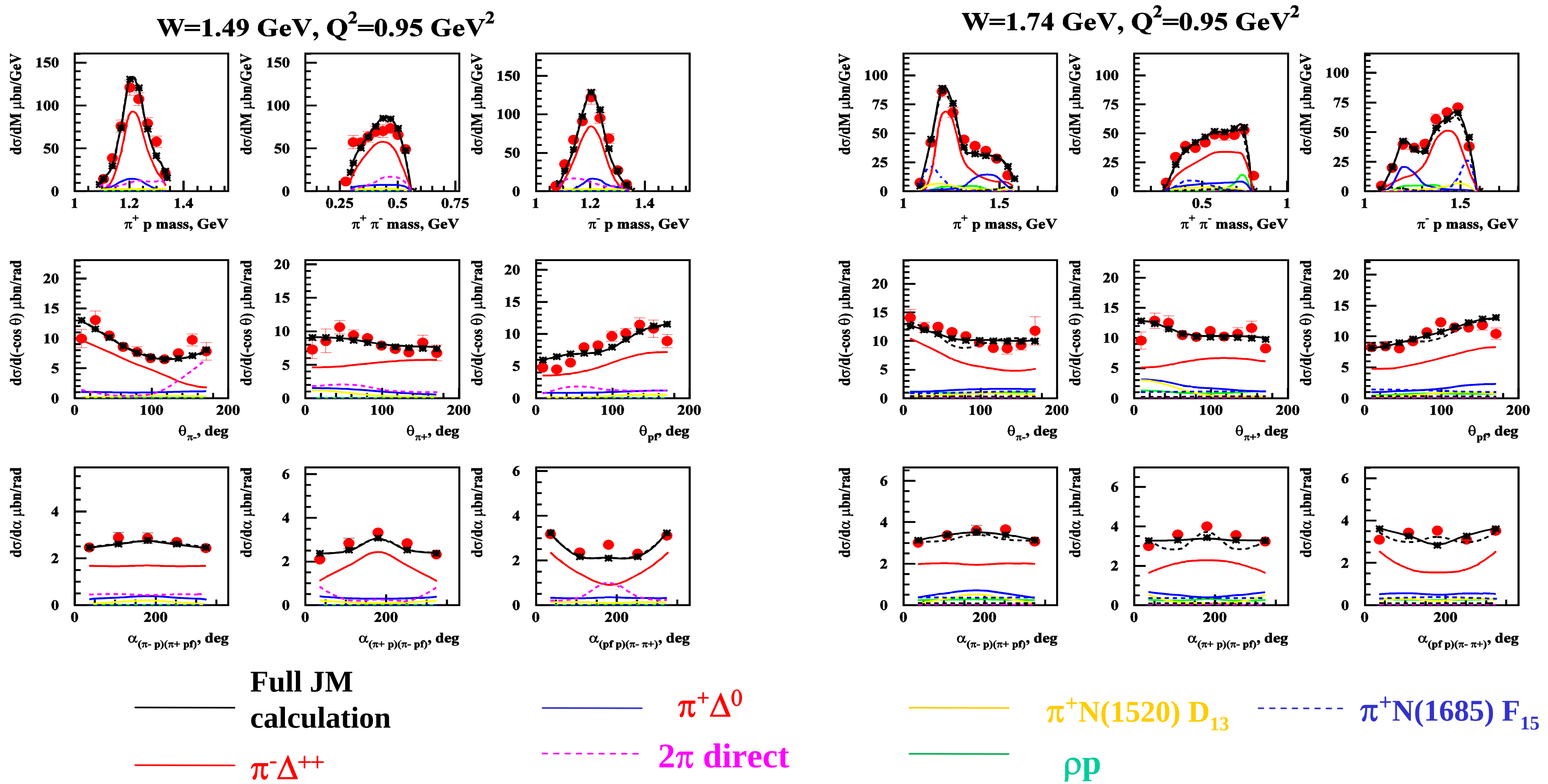
I. Aznauryan —— UIM fit

Two conceptually different approaches DR and UIM are consistent. CLAS data provide rigid constraints for checking validity of the approaches.

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

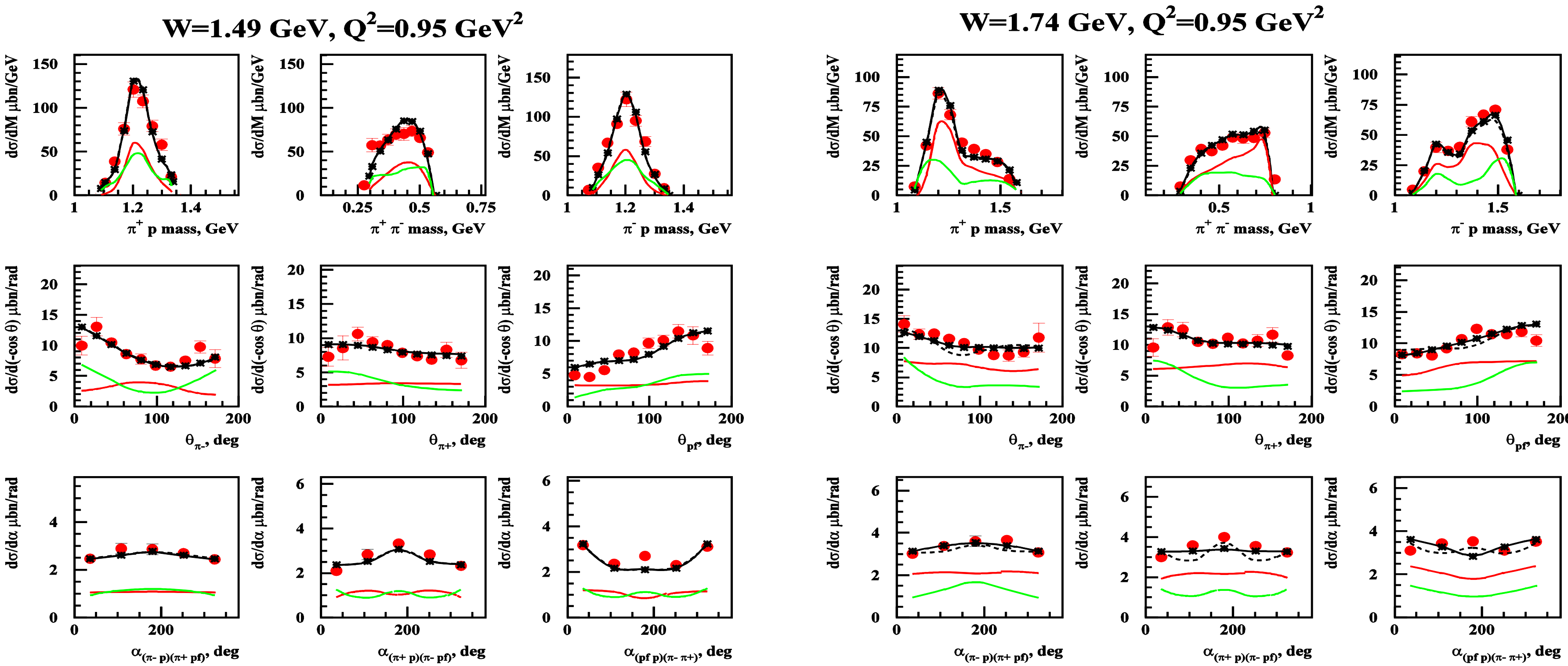


JM Mechanisms as Determined by the CLAS 2π Data



Any contributing mechanism has considerably different shapes of cross sections in various observables defined by the particular behavior of their amplitudes. A successful description of all observables allows us to check and to establish the dynamics of all essential contributing mechanisms.

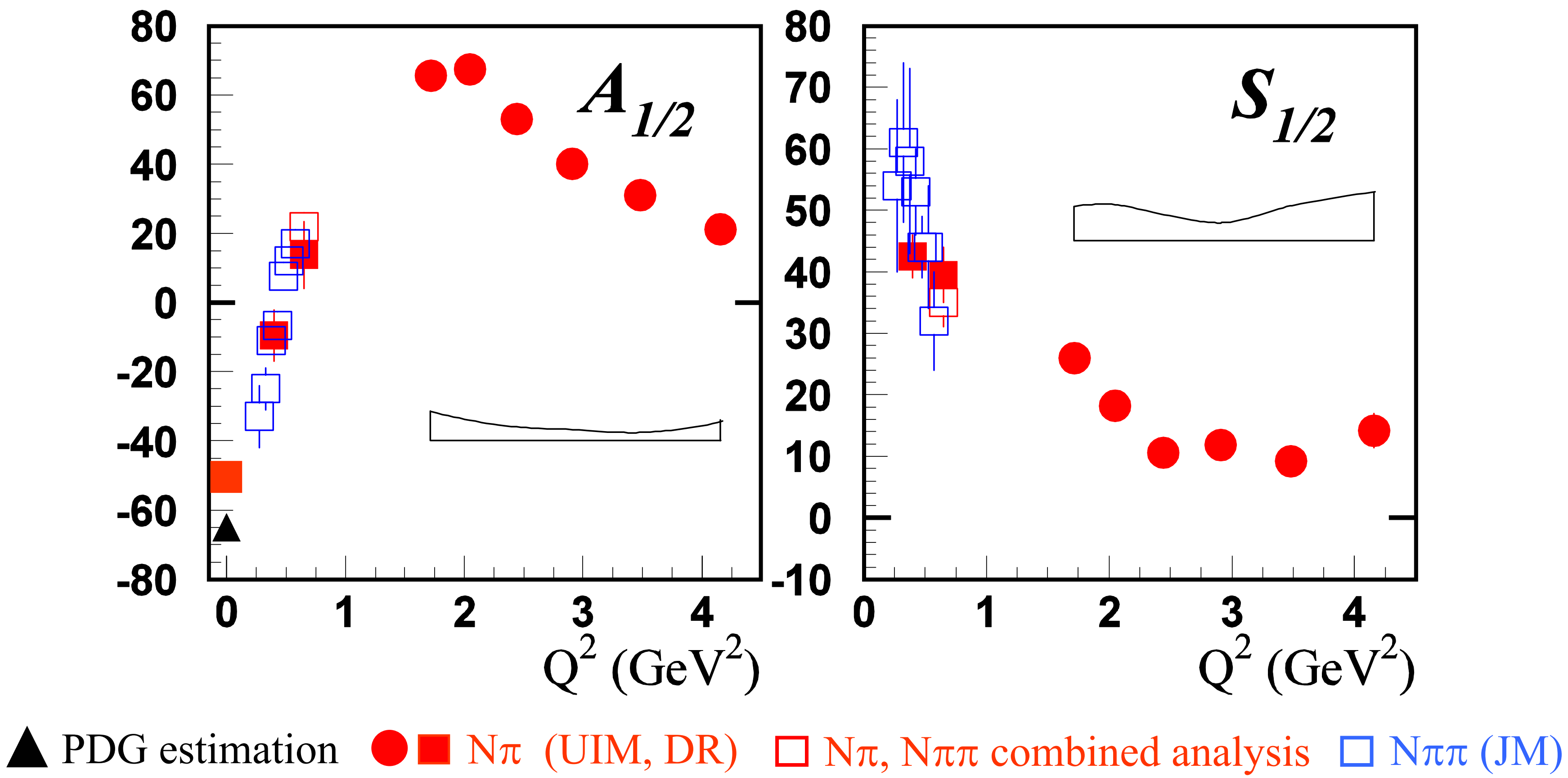
Separation of Resonant/Nonresonant Contributions in 2π Cross Sections



resonant part **nonresonant part**

Considerable resonant contributions and substantial differences in the shapes of resonant/nonresonant parts of the cross sections in all observables make it possible to isolate the resonant contributions and to determine the N* parameters.

Electrocouplings of $N(1440)P_{11}$ from CLAS Data



The good agreement on extracting the N* electrocouplings between the two exclusive channels (1π/2π) – having fundamentally different mechanisms for the nonresonant background – provides evidence for the reliable extraction of N* electrocouplings.

CLAS12 Detector

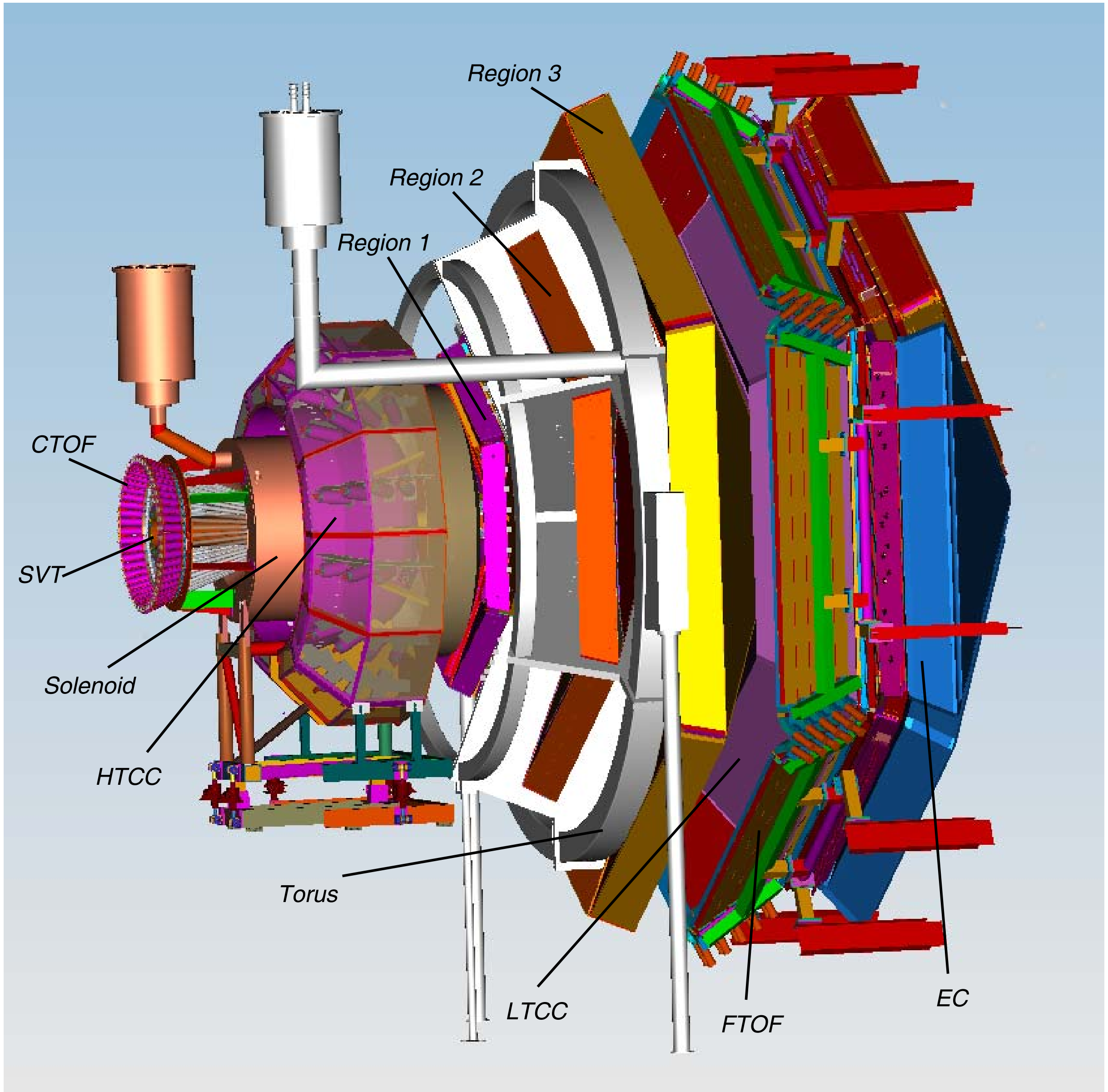
Base Equipment

SVT: MSU

HTCC: RPI
UConn

R1DC: ISU

FTOF: USC



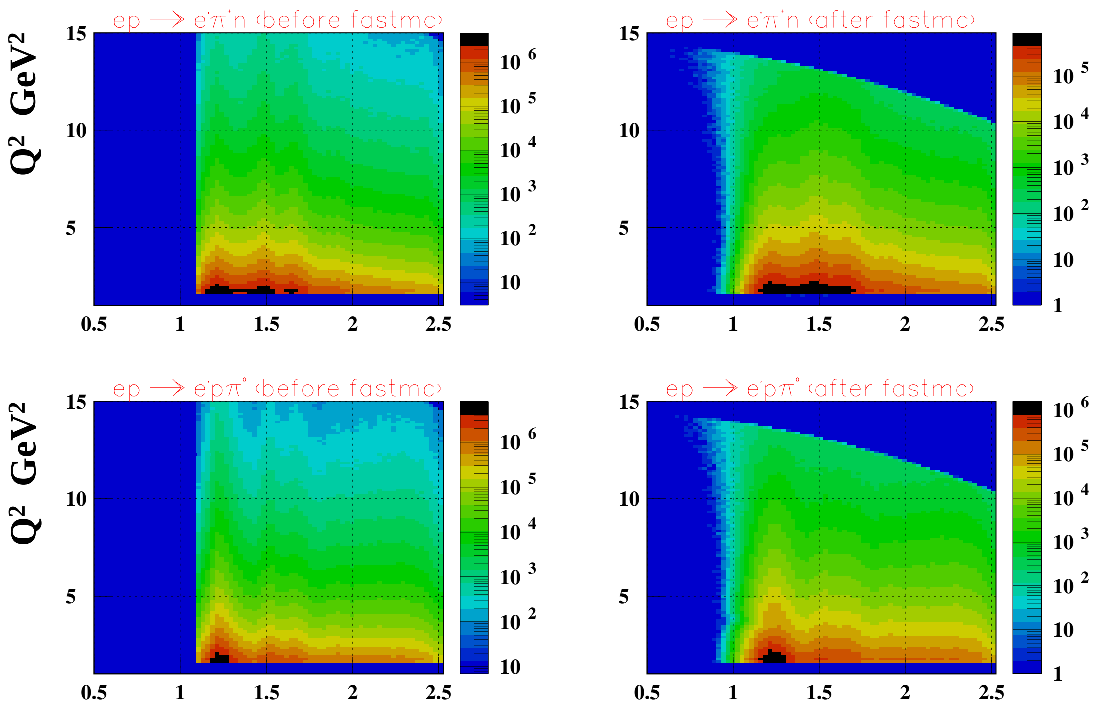
CLAS 12 Kinematic Coverage and Counting Rates

Genova-EG

(e',π^+) detected

Genova-EG

(e',p) detected

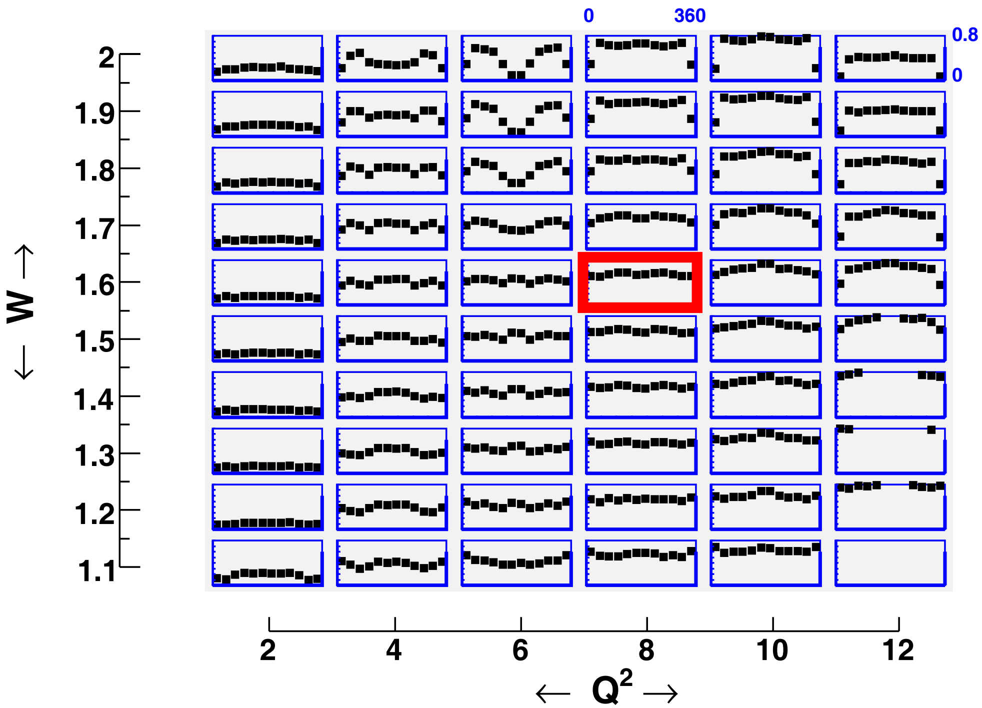


(E,Q^2)	(5.75 GeV, 3 GeV^2)	(11 GeV, 3 GeV^2)	(11 GeV, 12 GeV^2)
$N^{\pi+}$	$1.41*10^5$	$6.26*10^6$	$5.18*10^4$
$N^{p\pi 0}$	-	$4.65*10^5$	$1.45*10^4$
$N^{p\eta}$	-	$1.72*10^4$	$1.77*10^4$

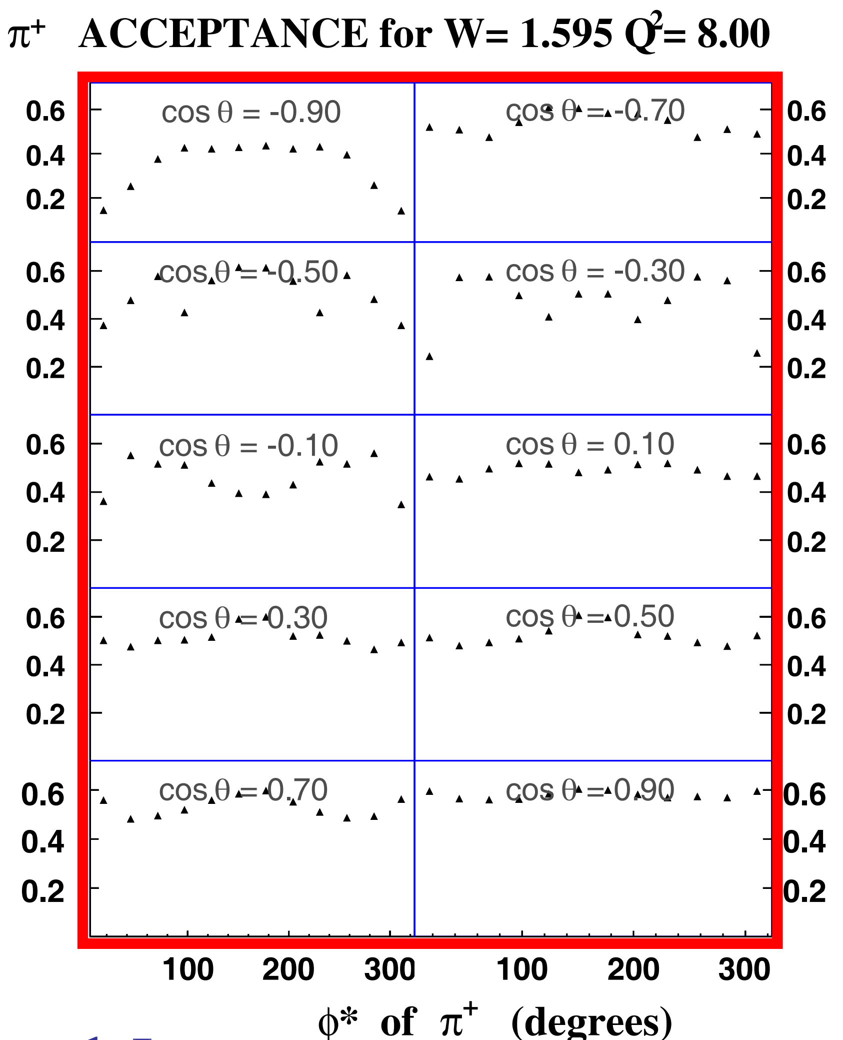
60 days

$L=10^{35}\ cm^{-2}\ sec^{-1}$, W=1535 GeV, ΔW= 0.100 GeV, ΔQ^2 = 0.5 GeV^2

Angular Acceptance of CLAS12



π^+ Acceptance for cos(θ) = 0.01



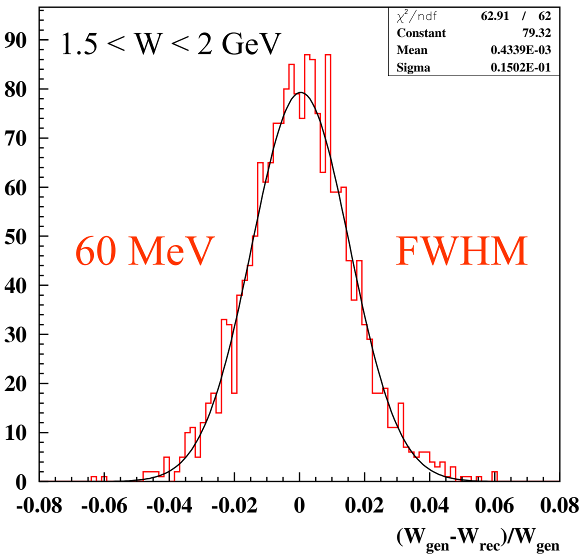
Full kinematical coverage in W, Q^2, Θ, and Φ

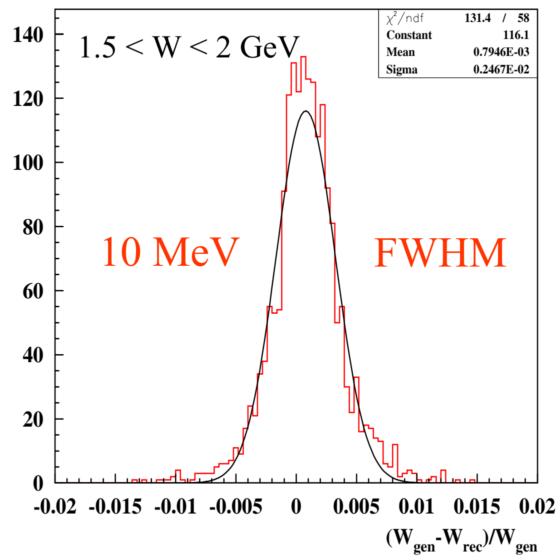
W and Missing Mass Resolutions with CLAS12

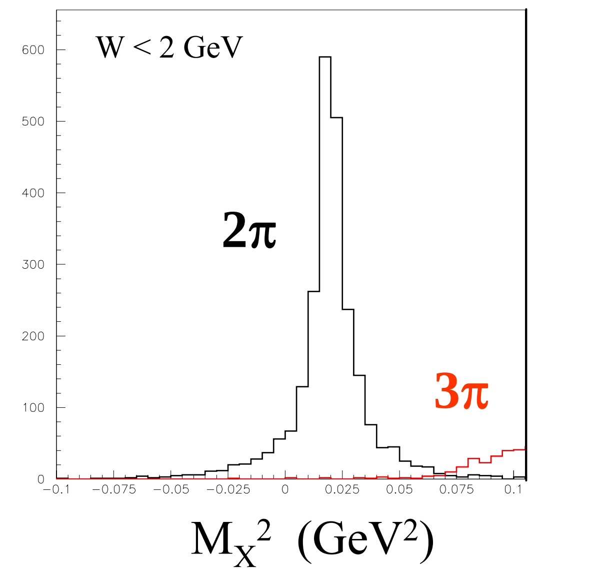
W calculated from

Final state selection

electron scattering | exclusive $p\pi^+\pi^-$ final state | by Missing Mass







$$W = \sqrt{(q_\gamma + P_p)^2}$$

$$W = \sqrt{(P_p + P_{\pi^+} + P_{\pi^-})^2}$$

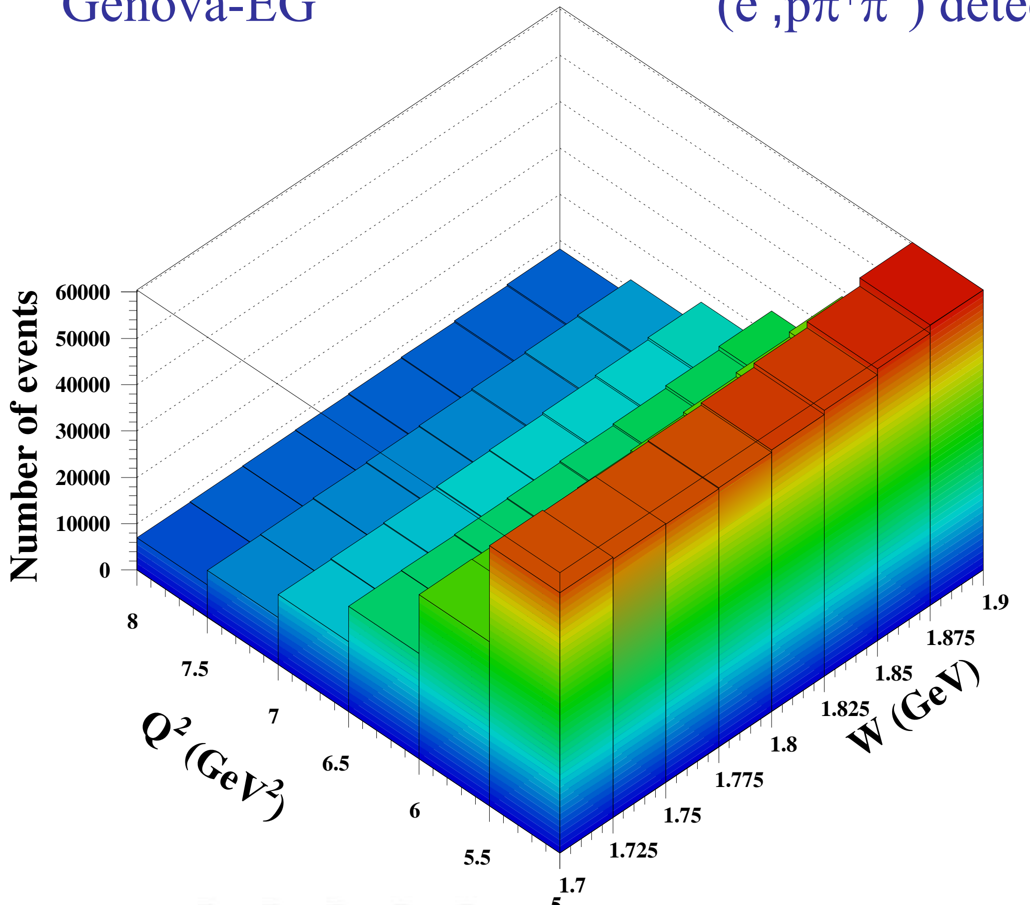
$$ep \rightarrow e'p'\pi^+X$$

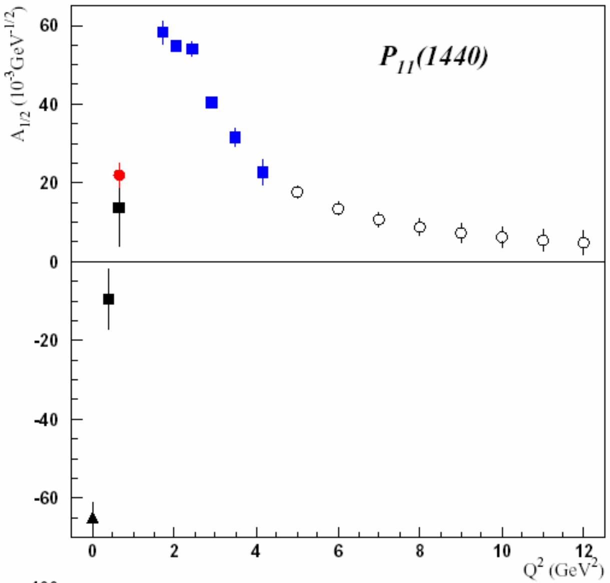
Kinematic Coverage of CLAS12

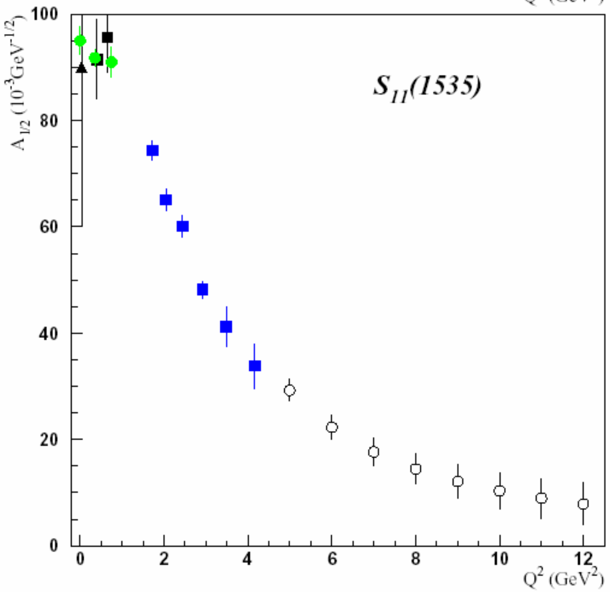
60 days

L= 10^{35} cm^{-2} sec^{-1}, $\Delta W = 0.025$ GeV, $\Delta Q^2 = 0.5$ GeV^2

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







Summary

- We propose a 60-day run with CLAS12 base equipment to obtain high quality data on
  - electroproduction cross sections and beam-spin asymmetries of $p\pi^0$, $n\pi^+$, $p\eta$ for W =1.1 – 2.0 GeV, $Q^2 < 12$ GeV^2, and full coverage in $\cos\theta^*_{\pi,\eta}$ and $\varphi^*_{\pi,\eta}$,
  - 9 single differential cross sections of $p\pi^+\pi^-$ channels for W =1.3 – 2.0 GeV, $Q^2 < 8$ GeV^2, and full angle coverage.
  - This proposed experiment could run concurrently with already approved experiments: E12-06-119, E12-06-112, and E12-06-108.
- We will determine – by means of a variety of analysis techniques – the electro-couplings $A_{1/2}$, $A_{3/2}$, $S_{1/2}$ (and their uncertainties) as a function of Q^2 for prominent nucleon and Δ states. This program can only be carried out with CLAS12.
- Comparing our results with LQCD, DSE, LCSR, and rCQM will give insight into
  - the strong interaction of dressed quarks and their confinement in baryons,
  - the dependence of the light quark mass on momentum transfer, thereby shedding light on chiral-symmetry breaking, and
  - the emergence of bare quark dressing and dressed quark interactions from QCD.