N* Transition Form Factors at JLab:

The Evolution of Baryonic Degrees of Freedom

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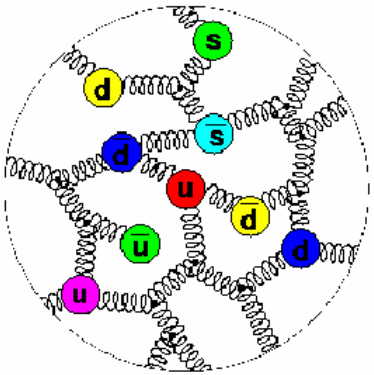
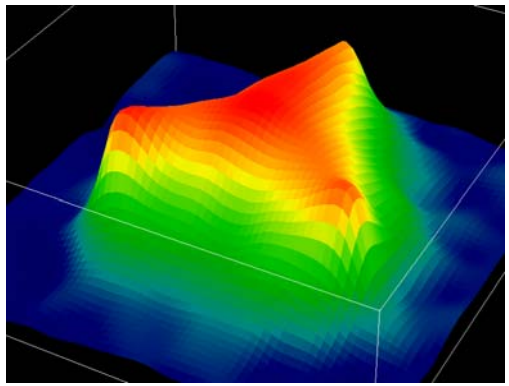
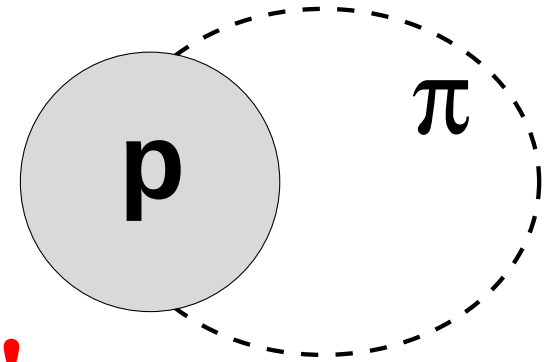
University of South Carolina

Exclusive Reactions at High Momentum Transfers
May 21-24, 2007
Jefferson Lab, Newport News, VA

- Introduction
- $N \rightarrow \Delta$, $N \rightarrow$ Roper, and other $N \rightarrow N^*$ Transitions
- 1π and 2π Production

Physics Goals

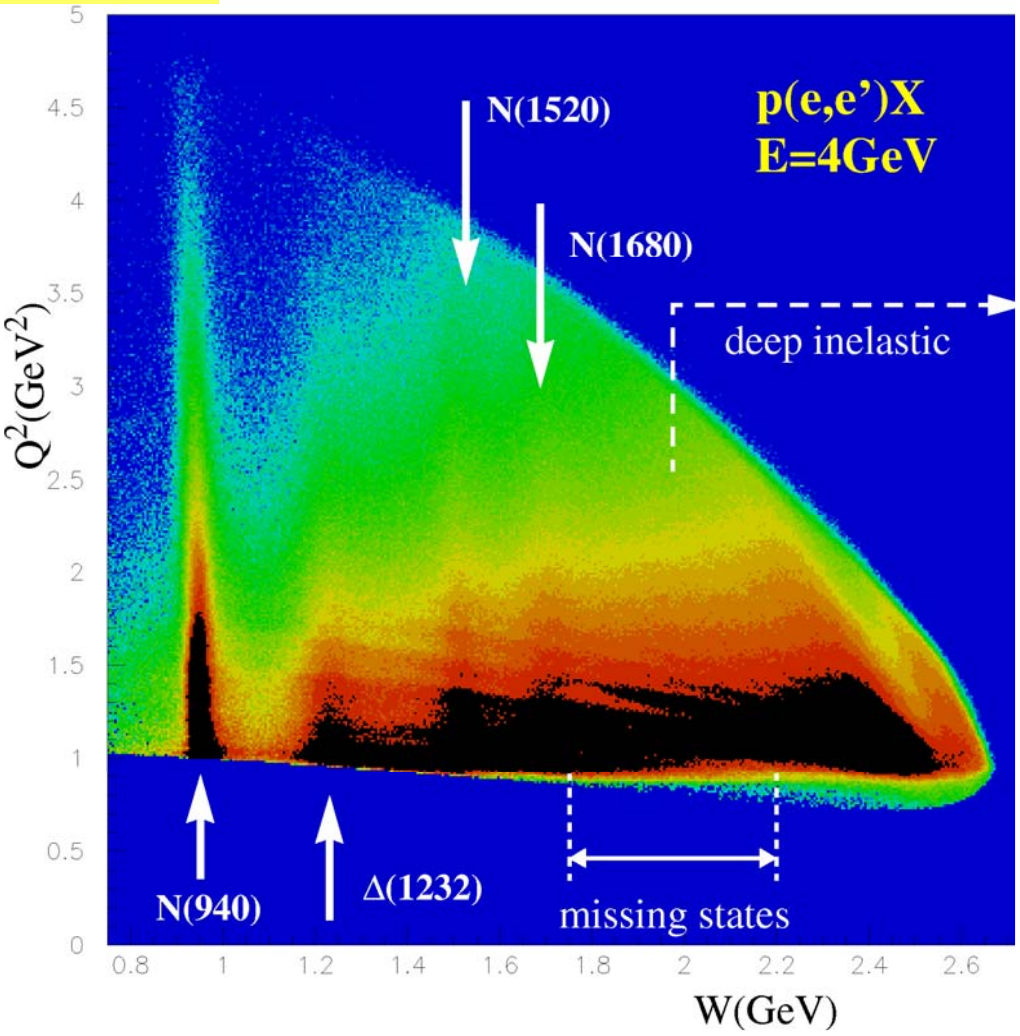
$\ll$ 0.1fm	0.1 – 1.0 fm	> 1.0 fm
		
pQCD q, g, qq̄	Models Quarks and Gluons as Quasiparticles	ChPT Nucleon and Mesons

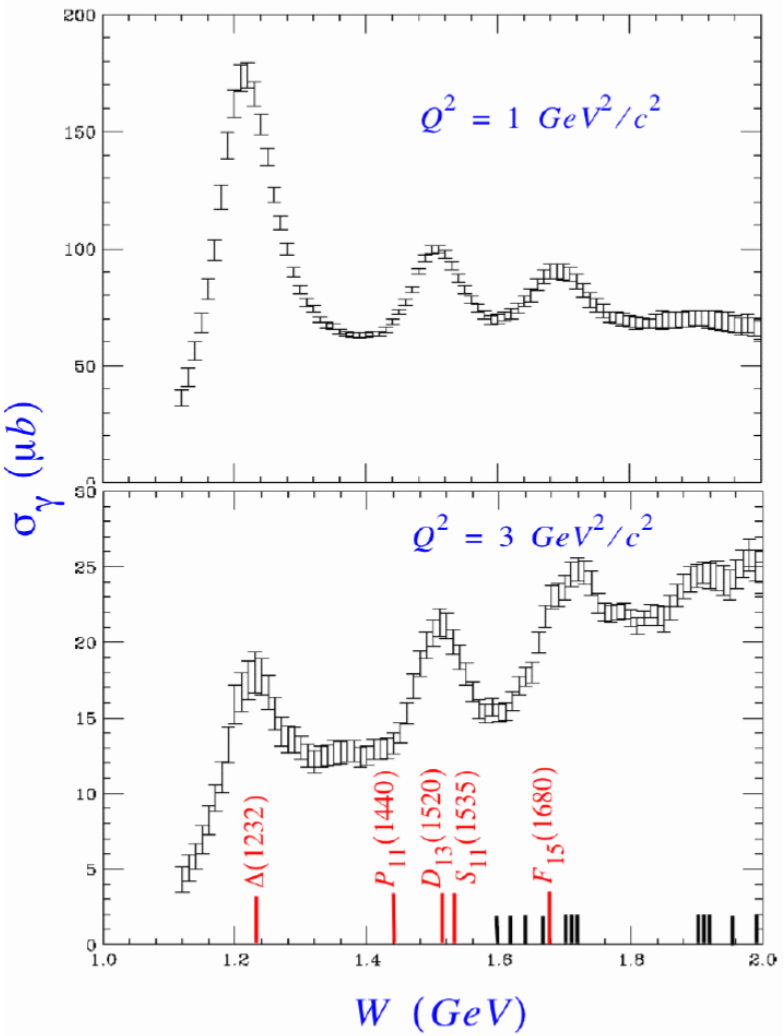
- Understand QCD in the full strong coupling regime
  - transition form factors to nucleon excited states

  allow us to study
  - relevant degrees-of-freedom
  - wave function and interaction of the constituents

CLAS for Inclusive ep → e'X at 4 GeV

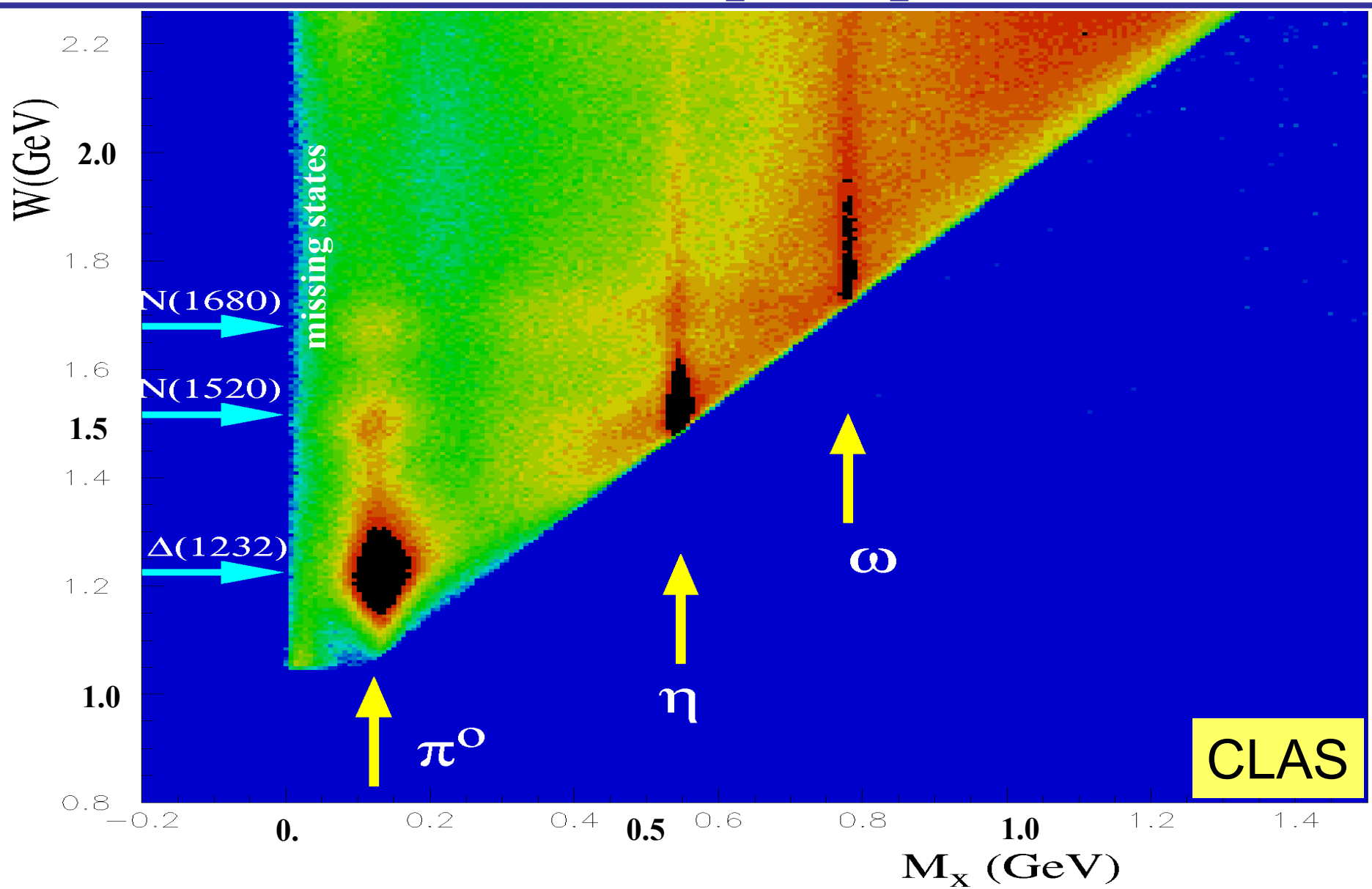
CLAS



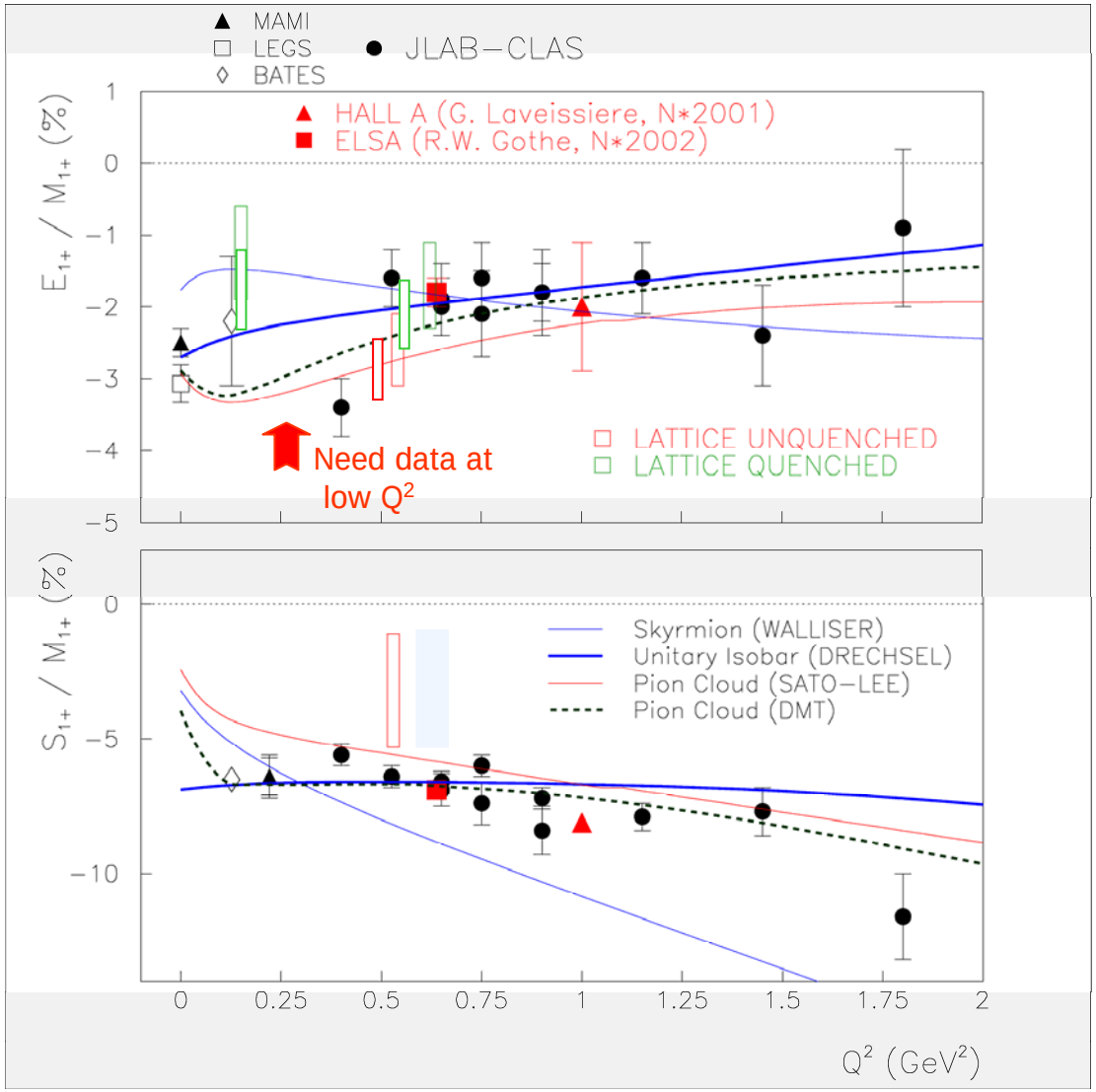


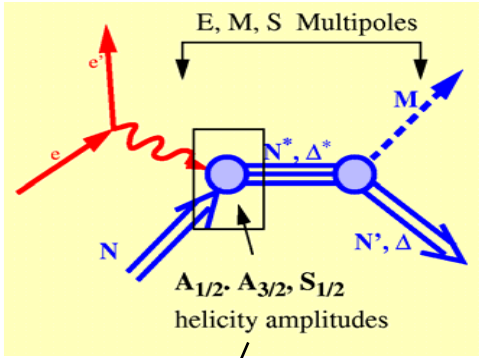
- Resonances cannot be uniquely separated in inclusive scattering

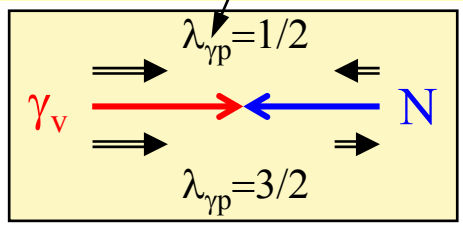
CLAS for Exclusive ep → e'pX at 4 GeV



N→Δ(1232) Transition Form Factors

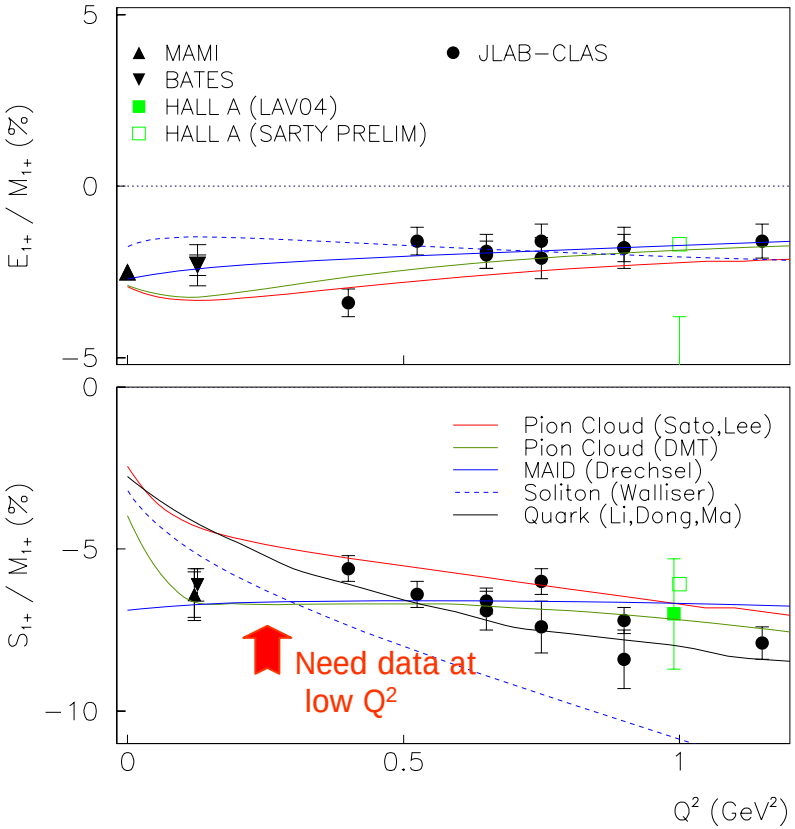




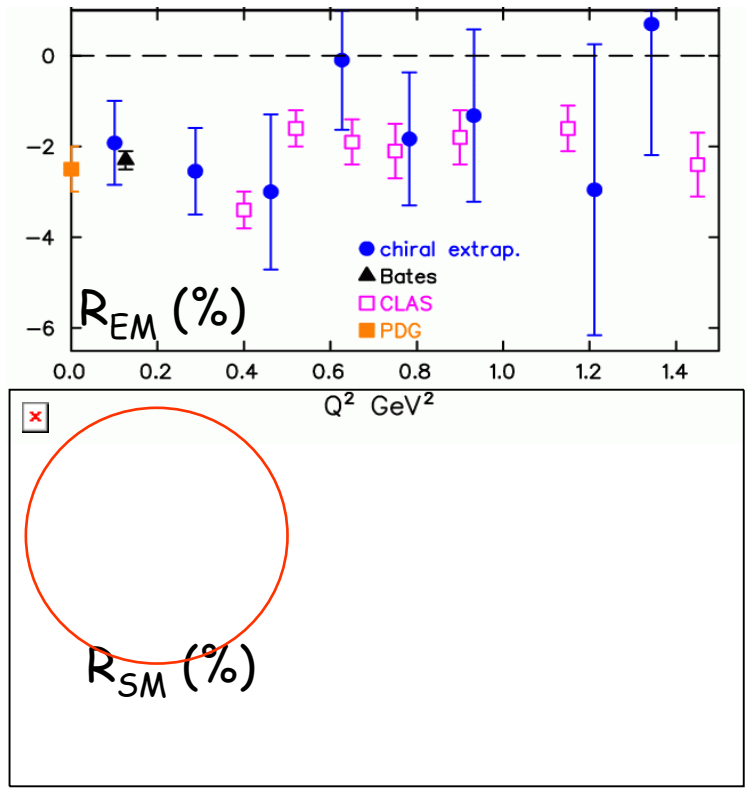


- Lattice QCD indicates a small oblate deformation of the Δ(1232) and that the pion cloud makes E_{1+}/M_{1+} more negative at small Q^2.
- Data at low Q^2 needed to study effects of the pion cloud.

Low-Q^2 Mutipole Ratios for R_{EM}, R_{SM}



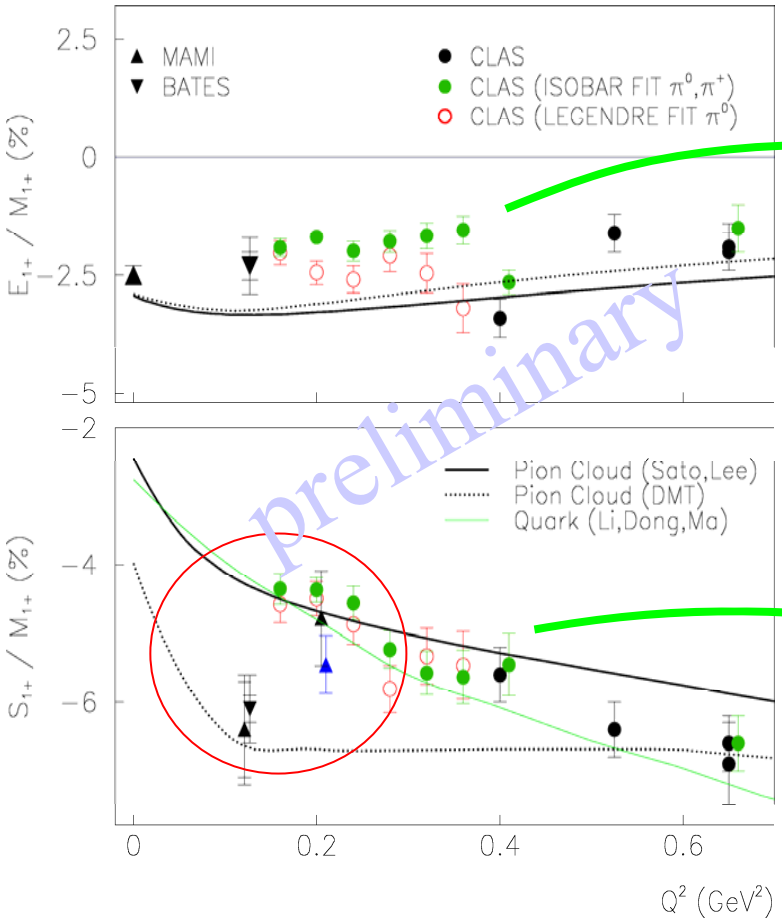
C. Alexandrou et al., PRL, 94, 021601 (2005)



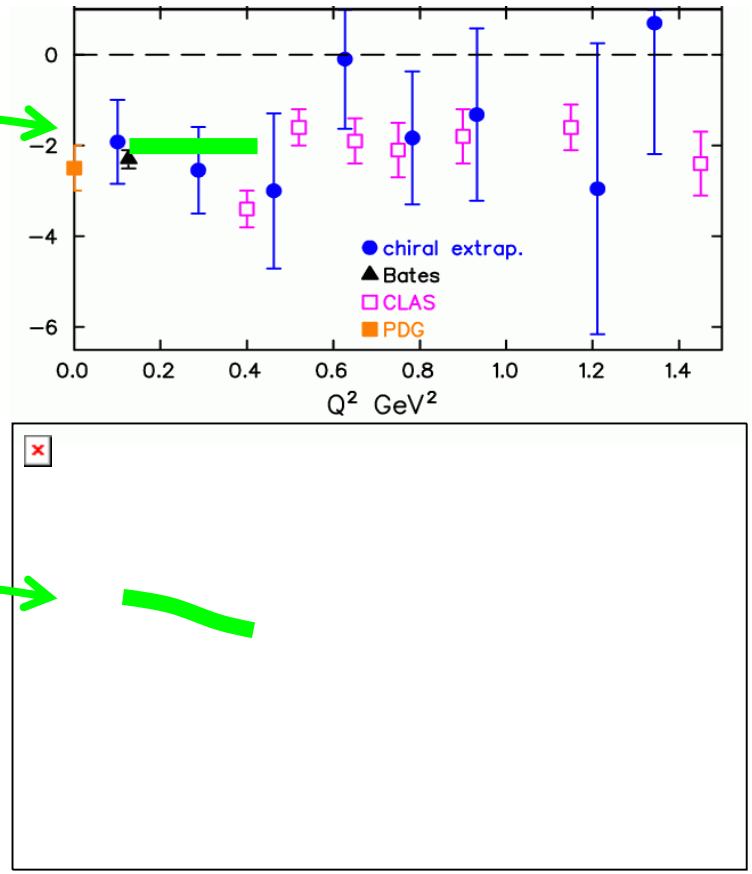
➢ Quenched LQCD describes R_{EM} within error bars, but shows discrepancies with R_{SM} at low Q^2 . Pion cloud effects?

Low-Q^2 Mutipole Ratios for R_{EM}, R_{SM}

C. Smith



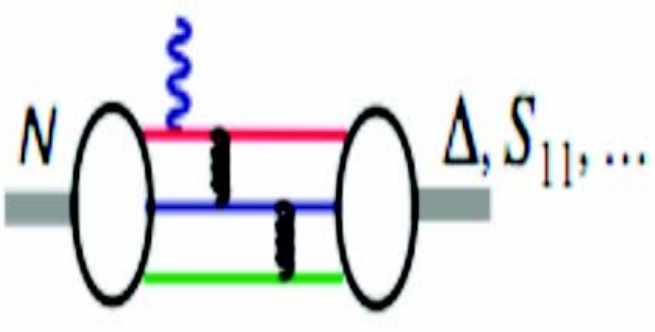
C. Alexandrou et al., PRL, 94, 021601 (2005)

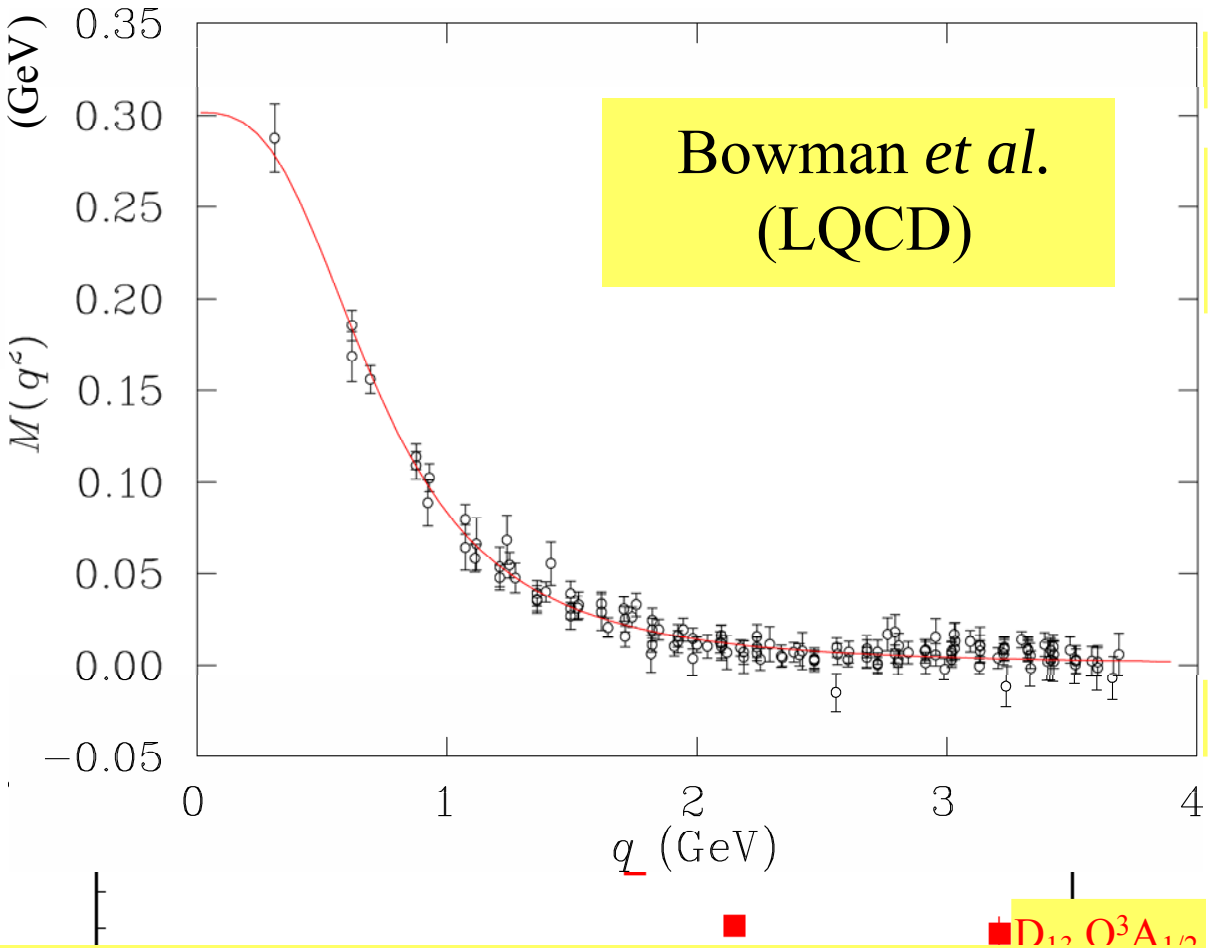


➢ Significant discrepancy between CLAS and Bates/MAMI results for R_{SM}.

➢ Quenched LQCD describes R_{EM} within error bars, but shows discrepancies with R_{SM} at low Q^2 . Pion cloud effects?

Constituent Counting Rule



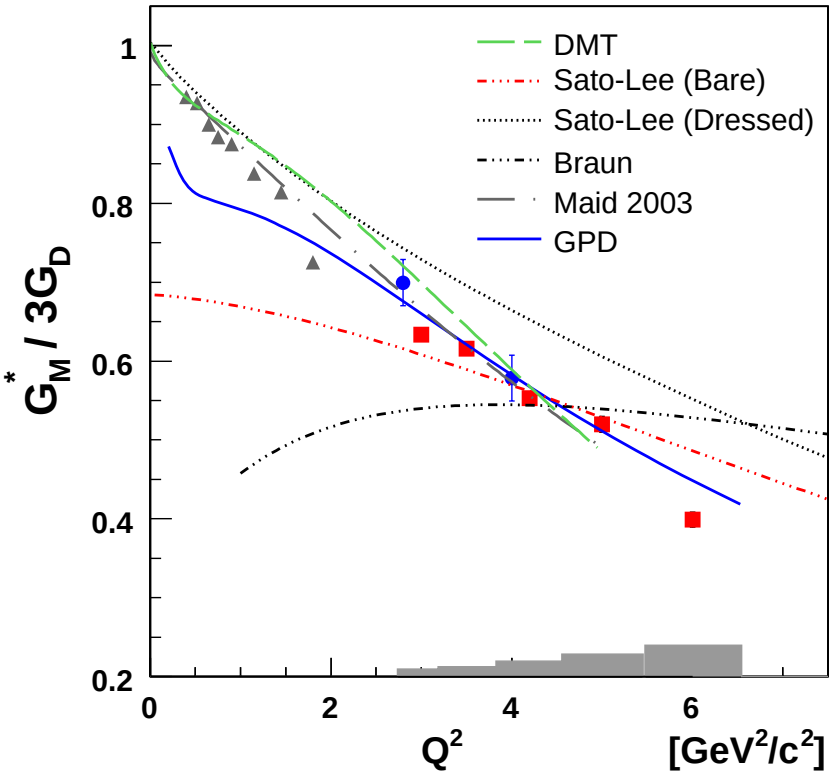


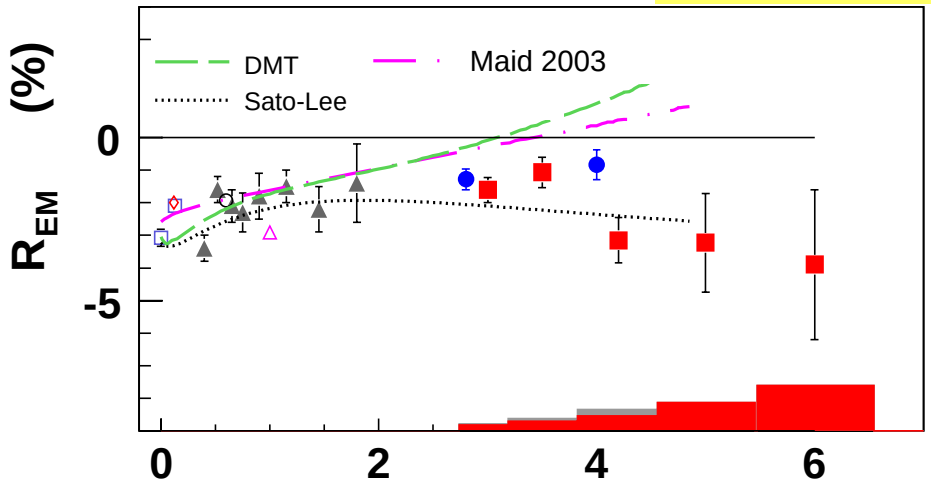
- $A_{1/2} \alpha 1/Q^3$
- $A_{3/2} \alpha 1/Q^5$
- $G_M^* \alpha 1/Q^4$

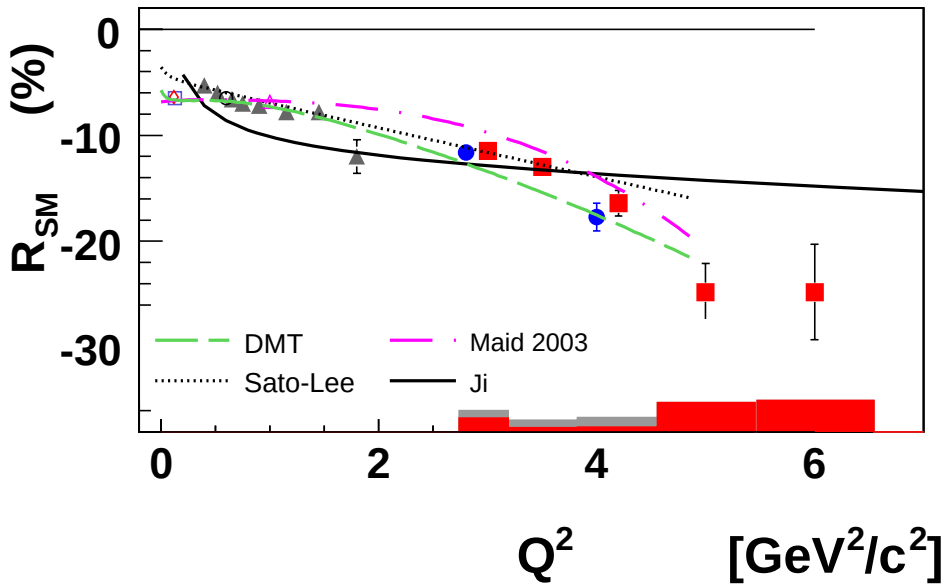
Quark mass extrapolated to the chiral limit, where q is the momentum variable of the tree-level quark propagator using the Asquat action.

$N \rightarrow \Delta$ Multipole Ratios R_{EM} , R_{SM}

M. Ungaro

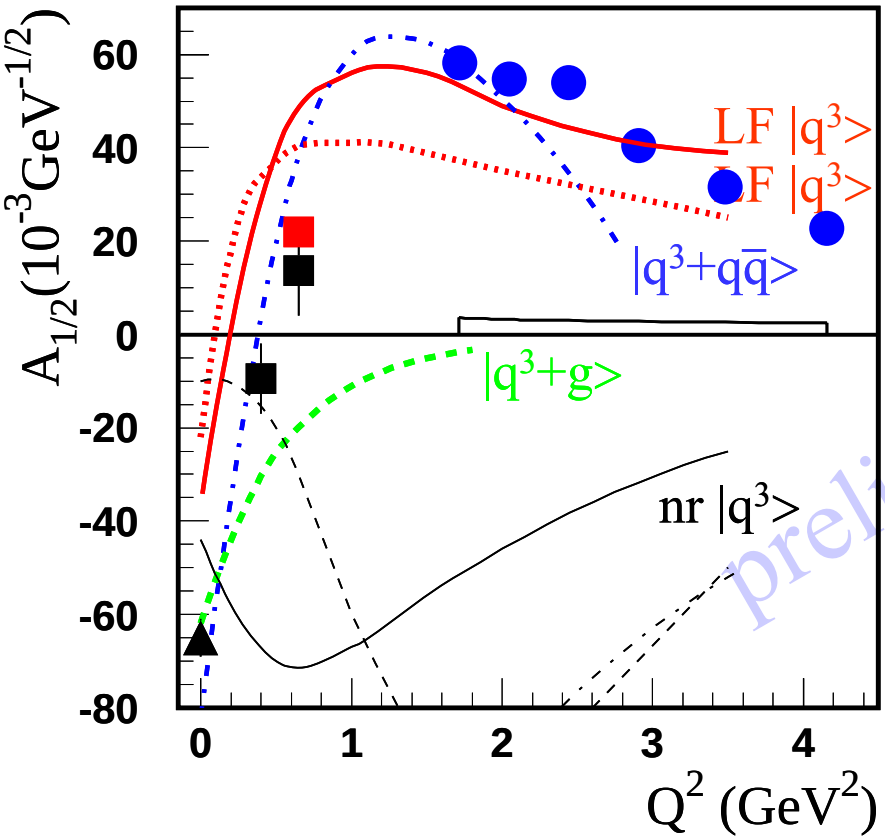


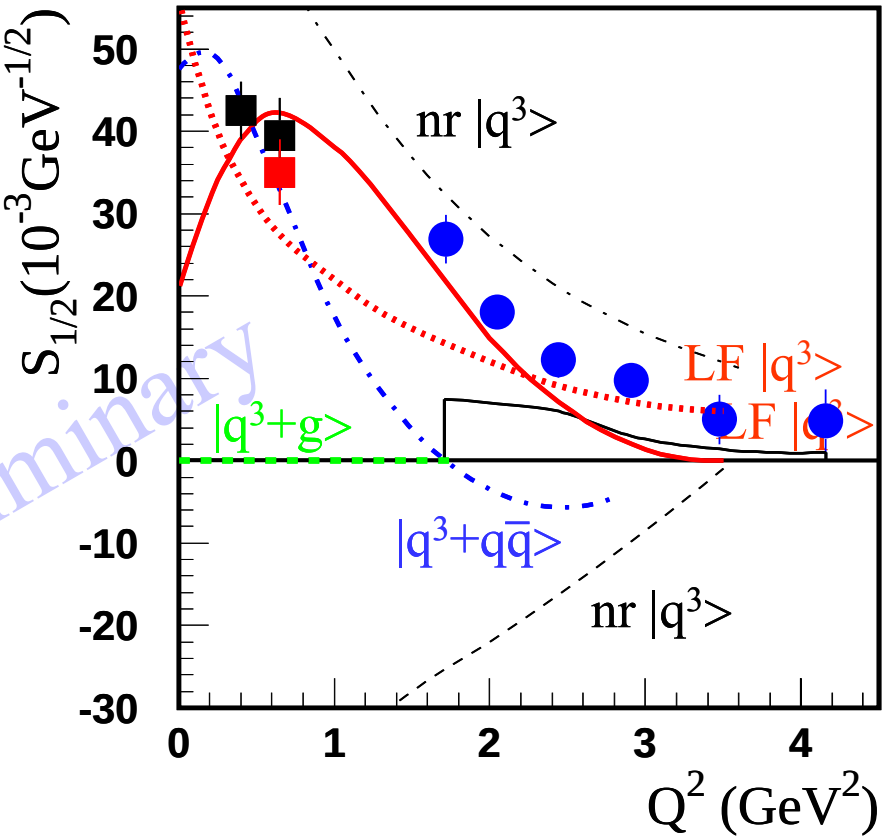




- New trend towards pQCD behavior does not show up.
  - $R_{EM} \rightarrow +1$
  - $G_M^* \rightarrow 1/Q^4$
- CLAS12 can measure R_{EM} and R_{SM} up to $Q^2 \sim 12$ GeV^2.

Roper Electro-Coupling Amplitudes $A_{1/2}$, $S_{1/2}$





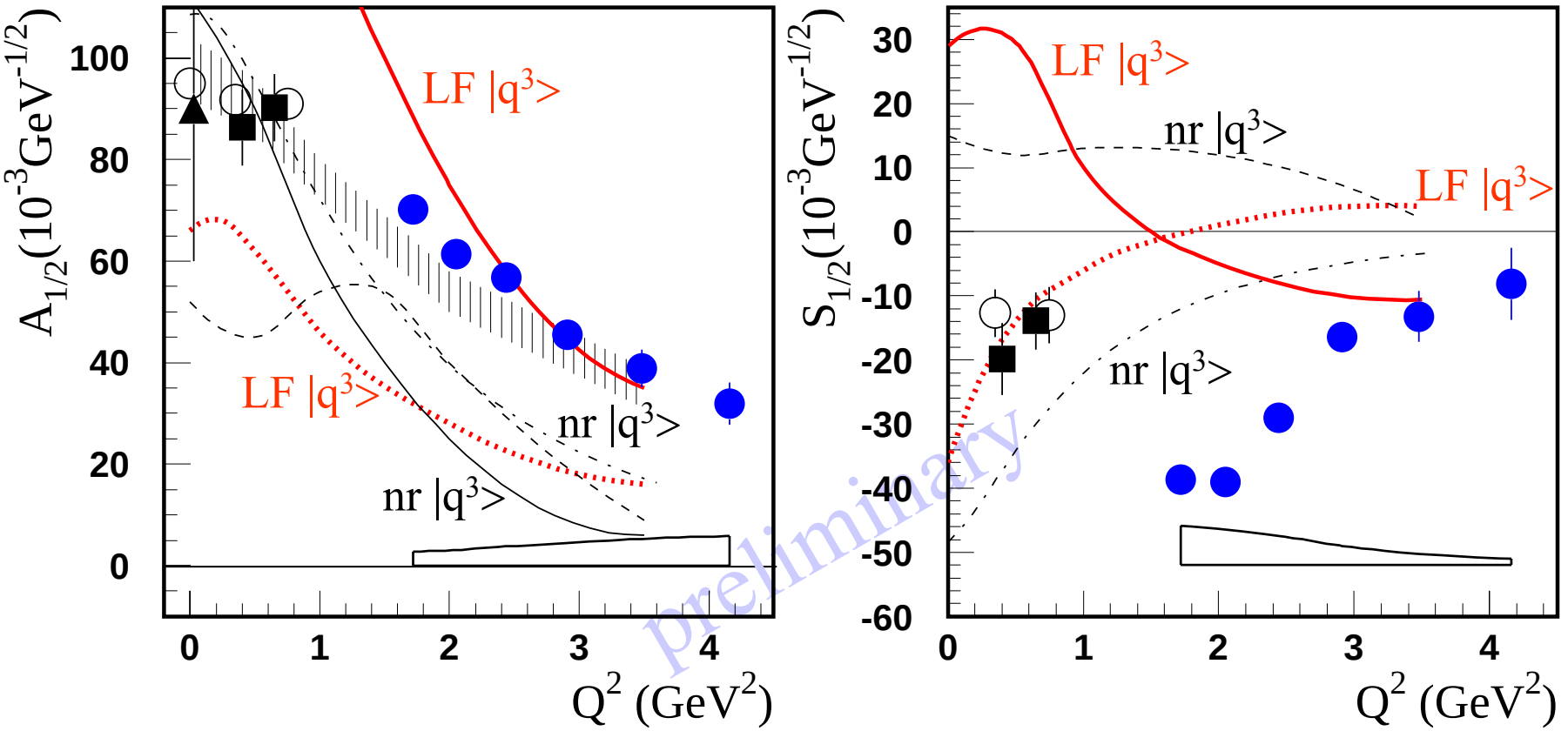
▲ PDG estimation

■ π electro-production (UIM, DR)

■ π, 2π combined analysis

● K. Park (Data)
I. Aznauryan (UIM)

$S_{11}(1535)$ Electro-Coupling Amplitudes $A_{1/2}$, $S_{1/2}$



▲ PDG estimation

■ π electro-production (UIM, DR)

▥ S_{11}, D_{13} combined analysis (SQTM)

○ η production (UIM, DR)

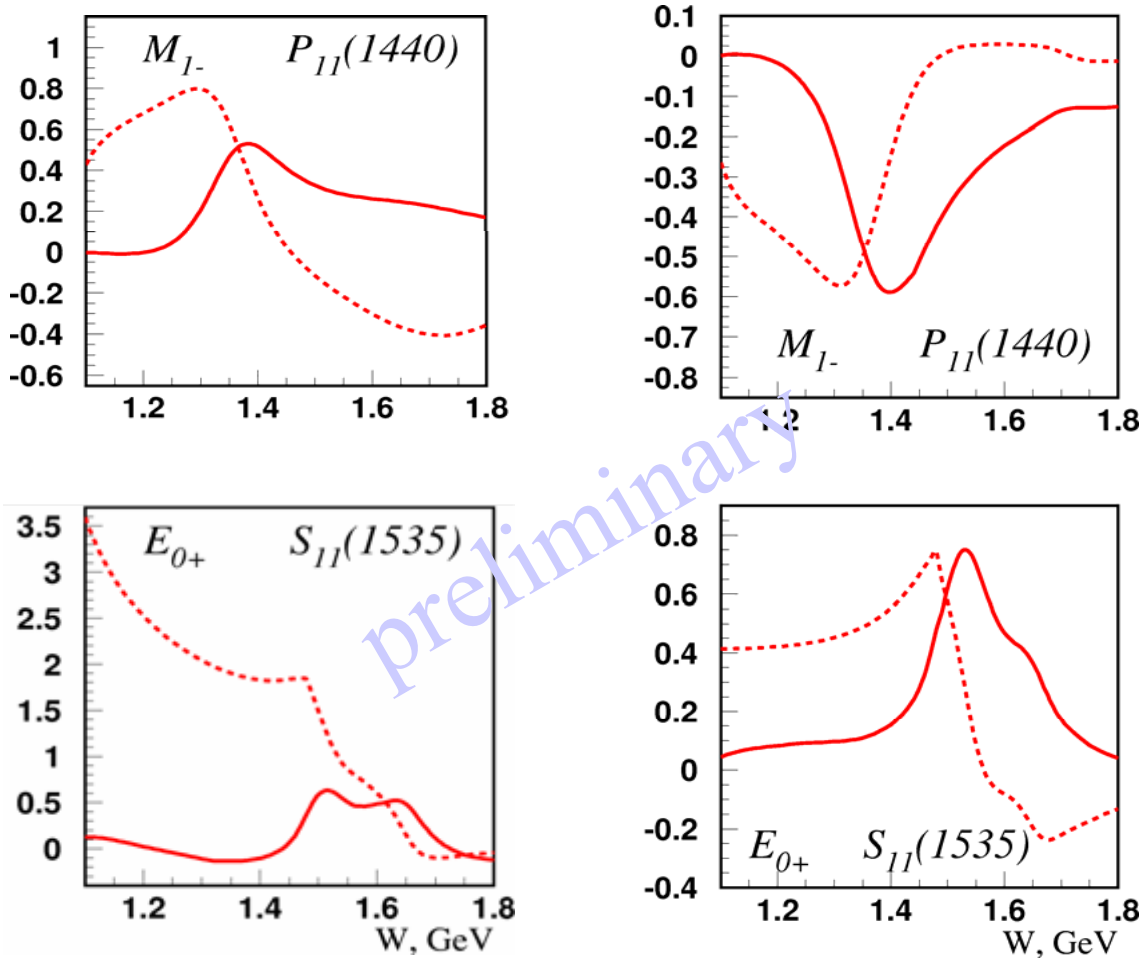
● K. Park (Data)
I. Aznauryan (UIM)

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

I. Aznauryan (UIM)

The study of some baryon resonances becomes easier at higher Q^2.

$Q^2 = 0$ GeV^2 $Q^2 = 2.05$ GeV^2



Legendre Moments of Structure Functions

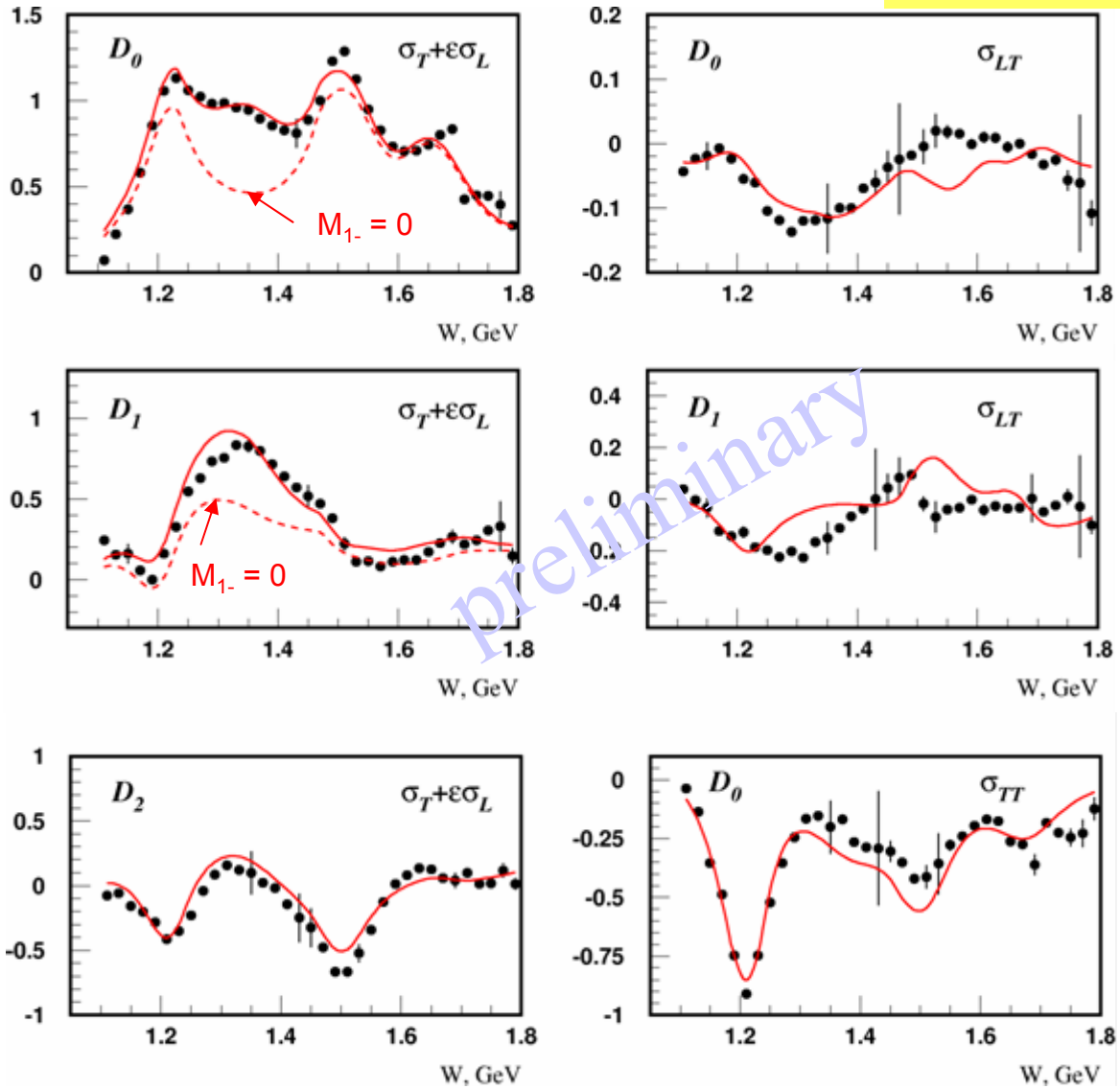
CLAS

K. Park

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

I. Aznauryan —— UIM fit

Q^2=2.05GeV^2

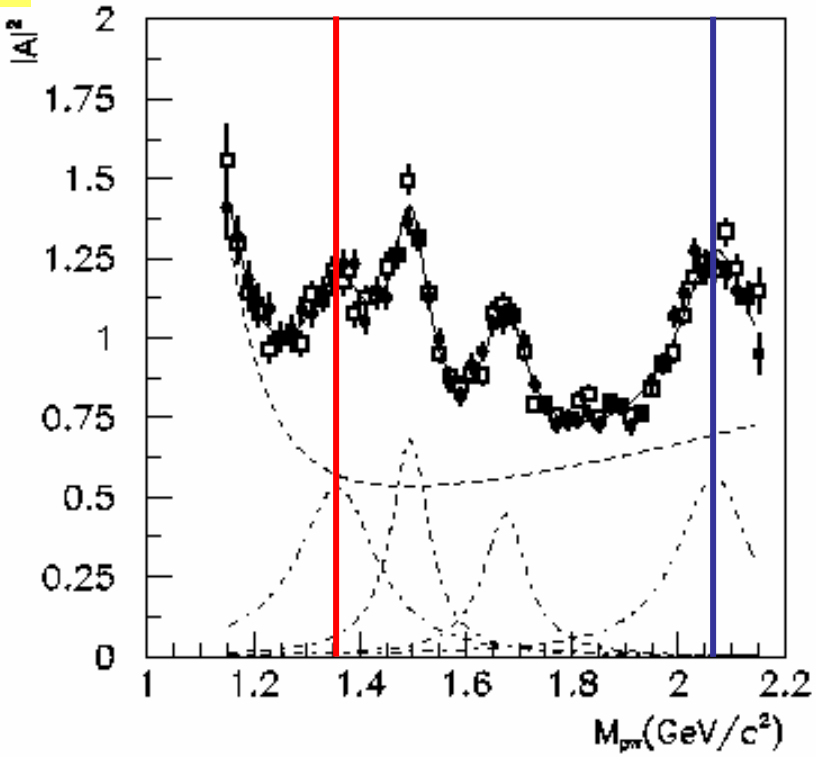


The dominating final state multipole amplitude M_{1-} of the $P_{11}(1440)$ resonance is at high Q^2 are much more prominent than at small Q^2.

$J/\psi \to p\pi^- \bar{n}$ and $J/\psi \to \bar{p}\pi^+ n$

BES

Bing-Song Zou



N*(1440): M = 1358 ∓ 17
Γ = 179 ∓ 56

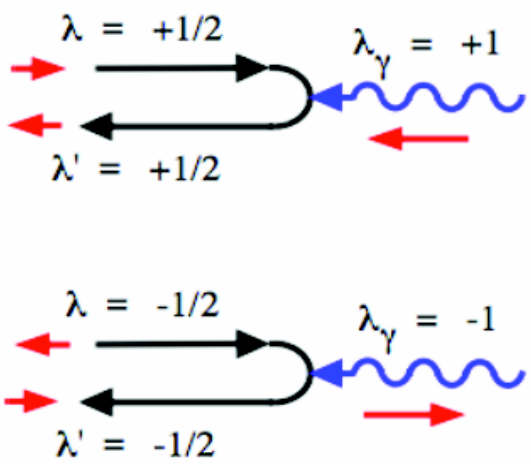
N*(2050): M = 2068 +15–40
Γ = 165 ∓ 42

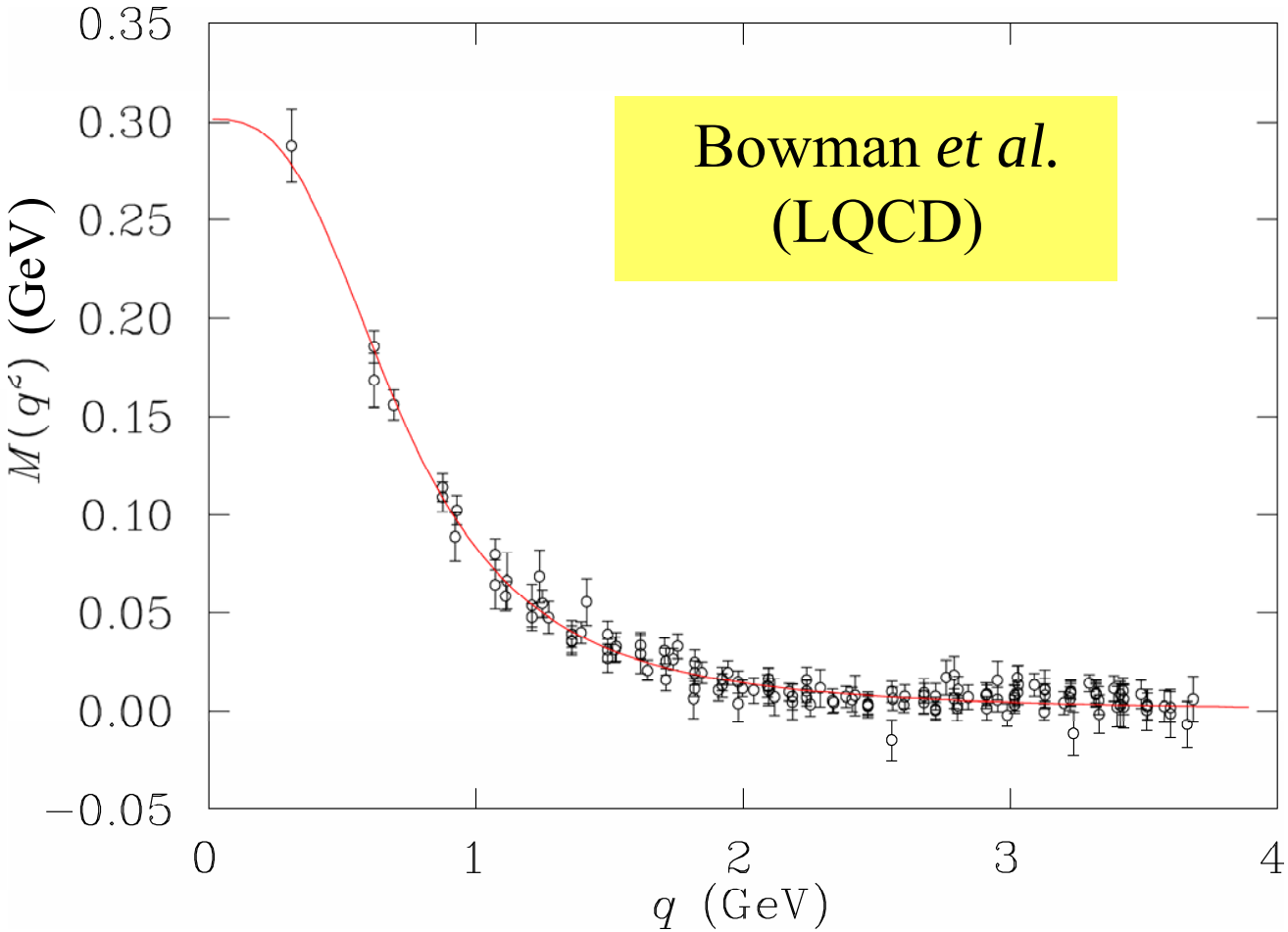
πN invariant mass / MC phase space

BES/BEPC, Phys. Rev. Lett. 97 (2006)

Fermion Helicity Conservation

Helicity Conservation
$\lambda = \lambda'$ for $q \gg M$





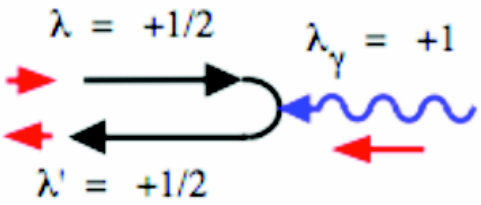
Bowman *et al.* (LQCD)

Quark mass extrapolated to the chiral limit, where q is the momentum variable of the tree-level quark propagator using the Asquat action.

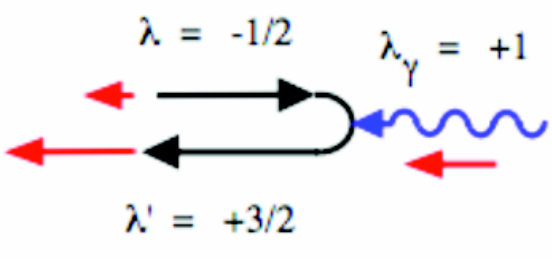
$D_{13}(1520)$ Helicity Asymmetry

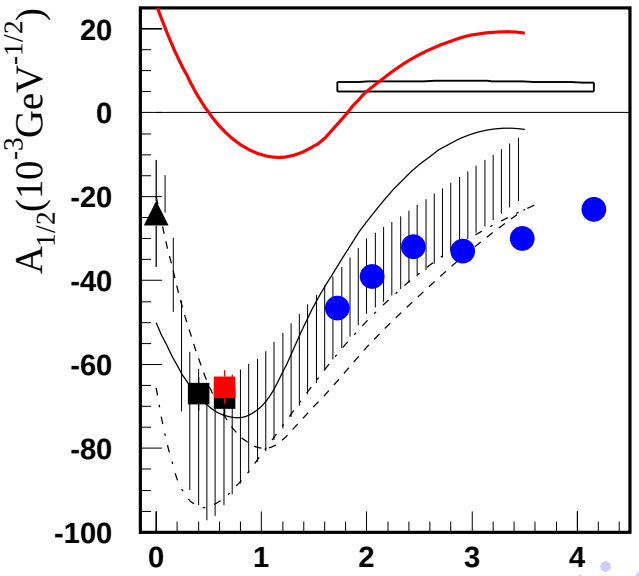
$$A_{hel} = \frac{A_{1/2}^2 - A_{3/2}^2}{A_{1/2}^2 + A_{3/2}^2}$$

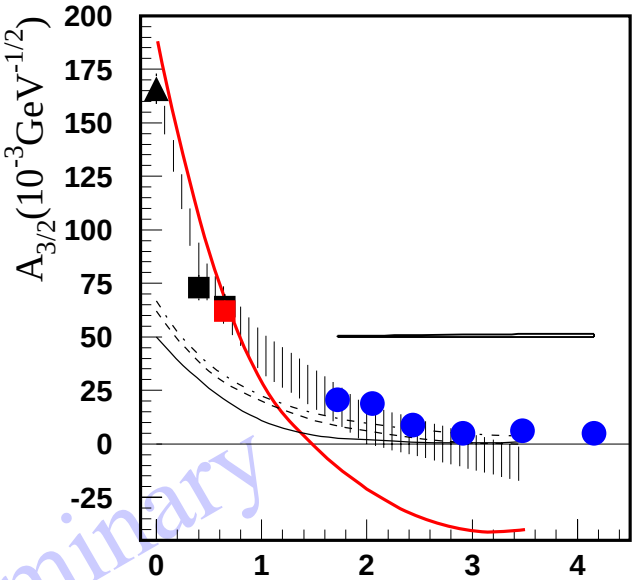
$A_{1/2}$

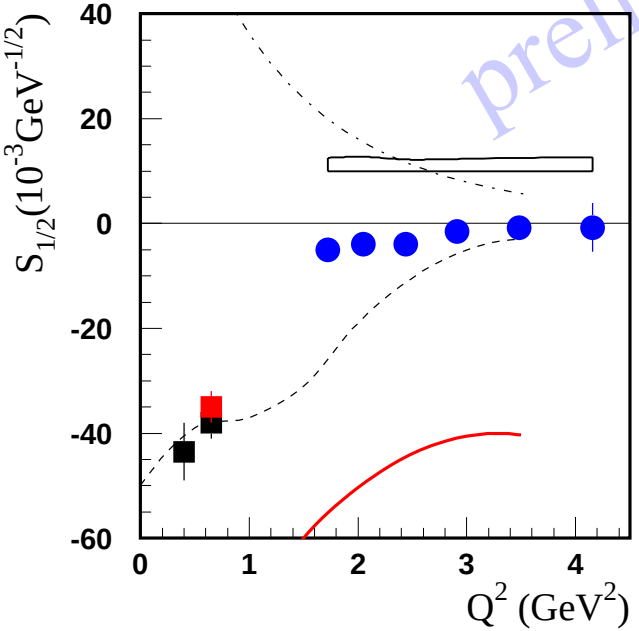


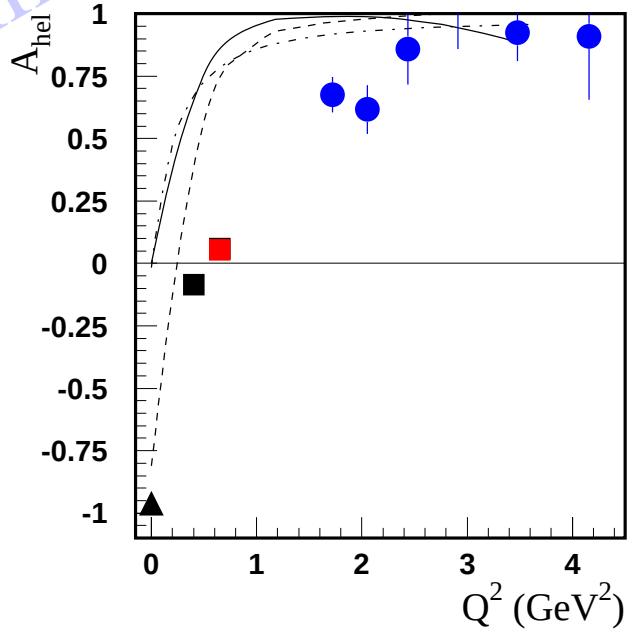
$A_{3/2}$





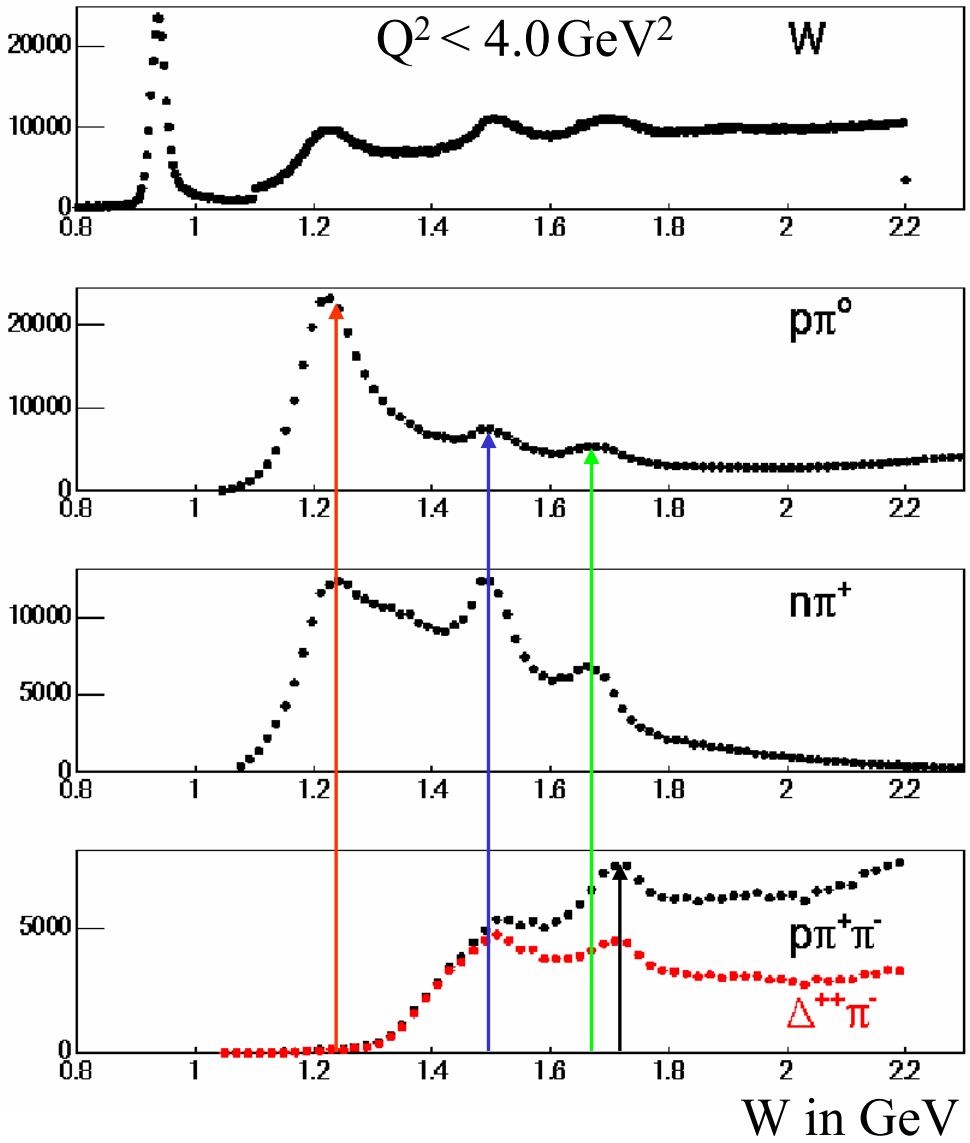






Nucleon Resonances in 2π Electroproduction

- 2π channel is sensitive to N*'s heavier than 1.4 GeV
- Provides complementary information to the 1π channel
- Many higher lying N*'s decay preferably to ππN final states



Trigger

p(e,e')X

p(e,e'p)π⁰

p(e,e'π⁺)n

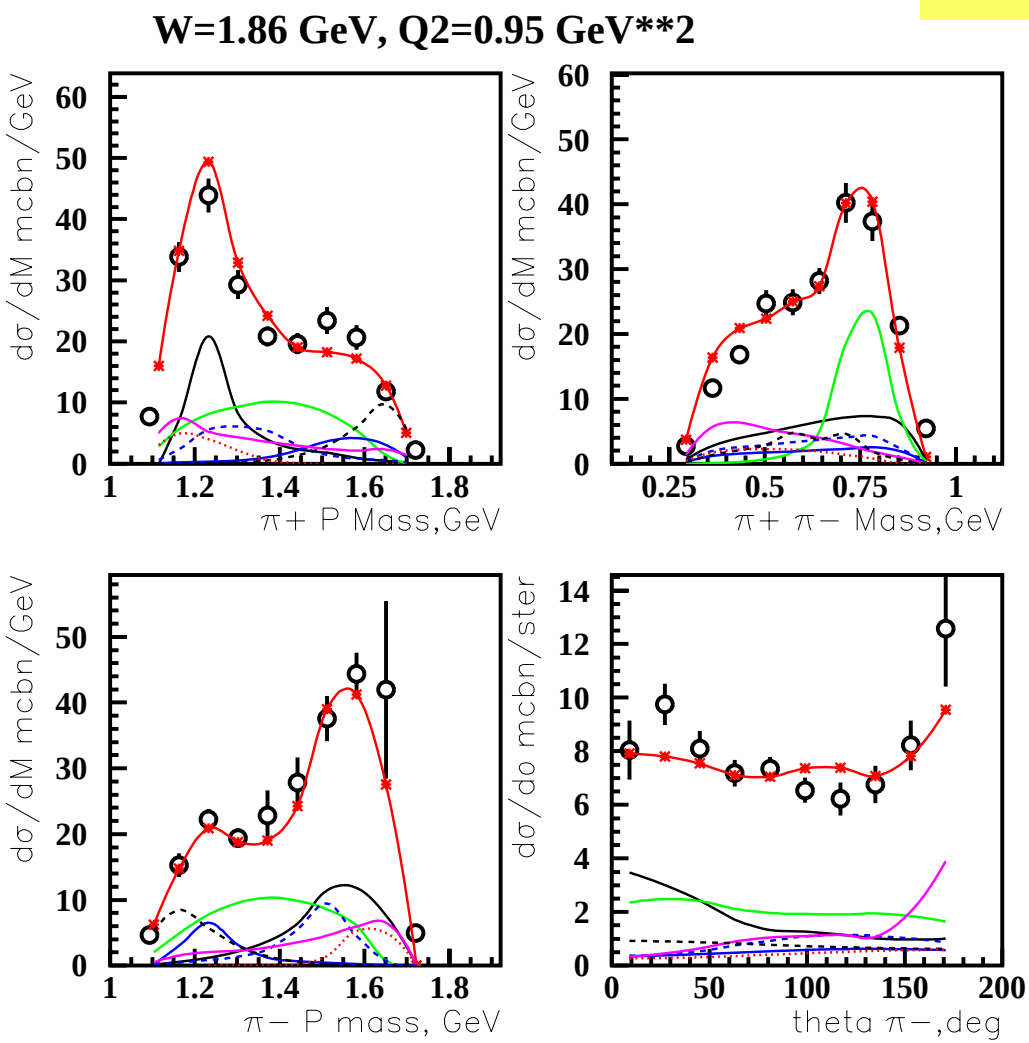
p(e,e'pπ⁺)π⁻

Contributing Mechanisms to $\gamma^{(*)}p \rightarrow p\pi^+\pi^-$

JM05

Isobar Model JM05

- Full calculations
- $\gamma p \rightarrow \pi^- \Delta^{++}$
- $\gamma p \rightarrow \pi^+ \Delta^0$
- $\gamma p \rightarrow \pi^+ D_{13}(1520)$
- $\gamma p \rightarrow \rho p$
- $\gamma p \rightarrow \pi^- \Delta^{++}(1600)$
- $\gamma p \rightarrow \pi^+ F^0_{15}(1685)$
- direct 2π production



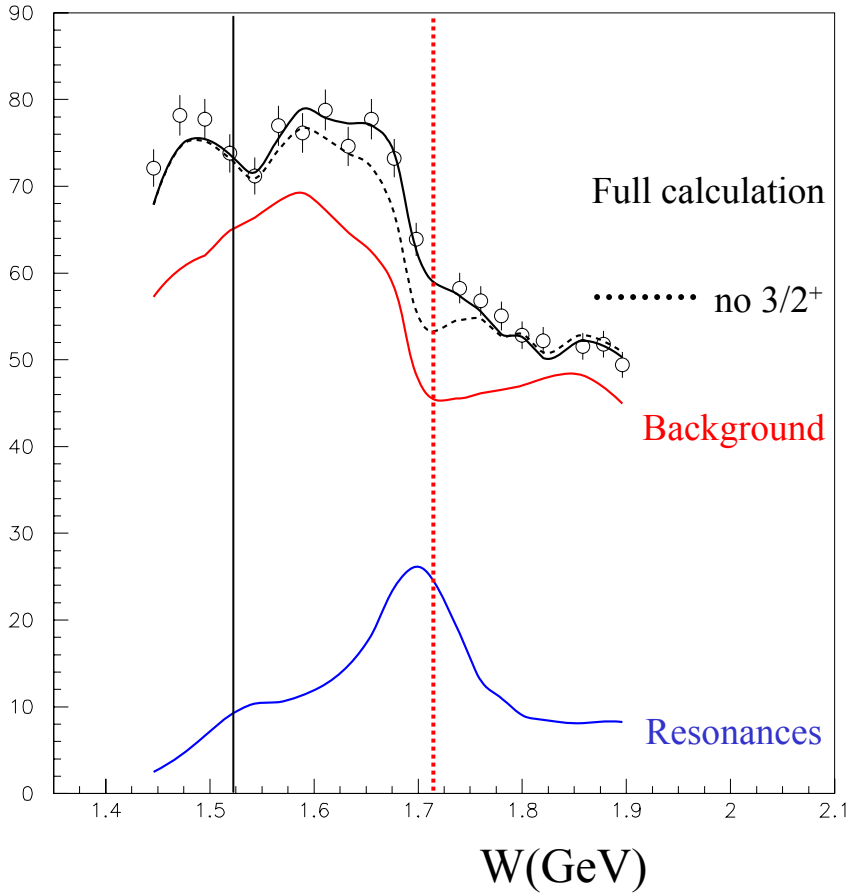
➢ Combined fit of various single differential cross sections allowed to establish all significant mechanisms

Resonances in $\gamma^{(*)}p \rightarrow p\pi^+\pi^-$

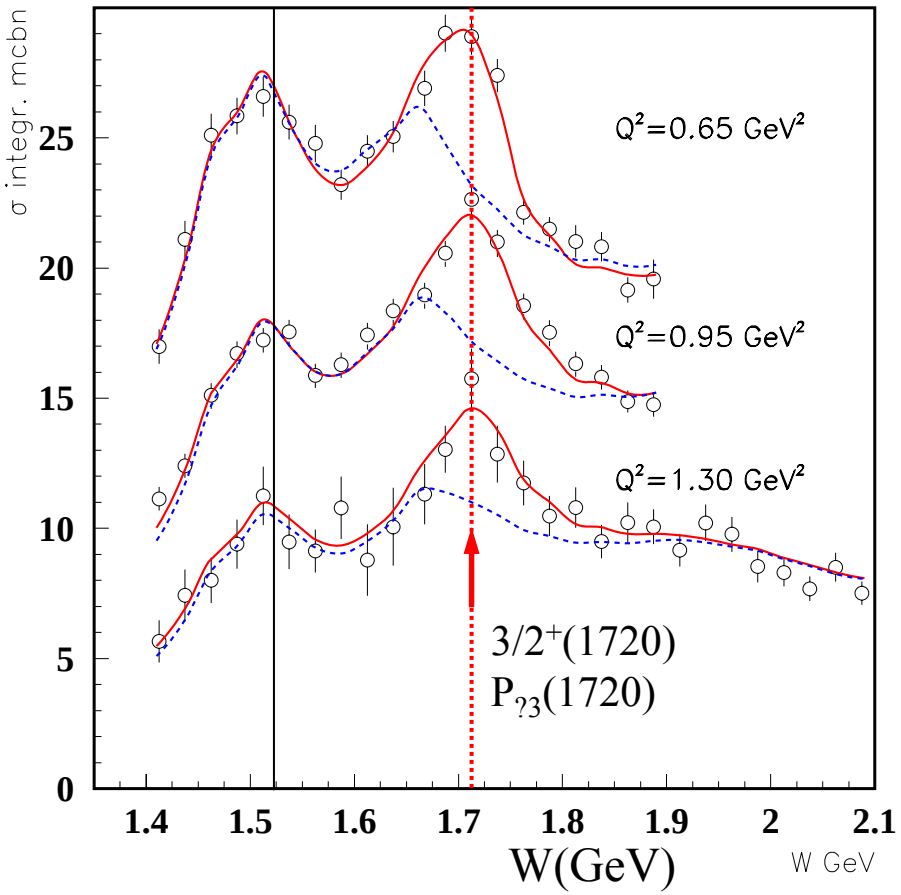
CLAS

M. Ripani

photo-production



electro-production



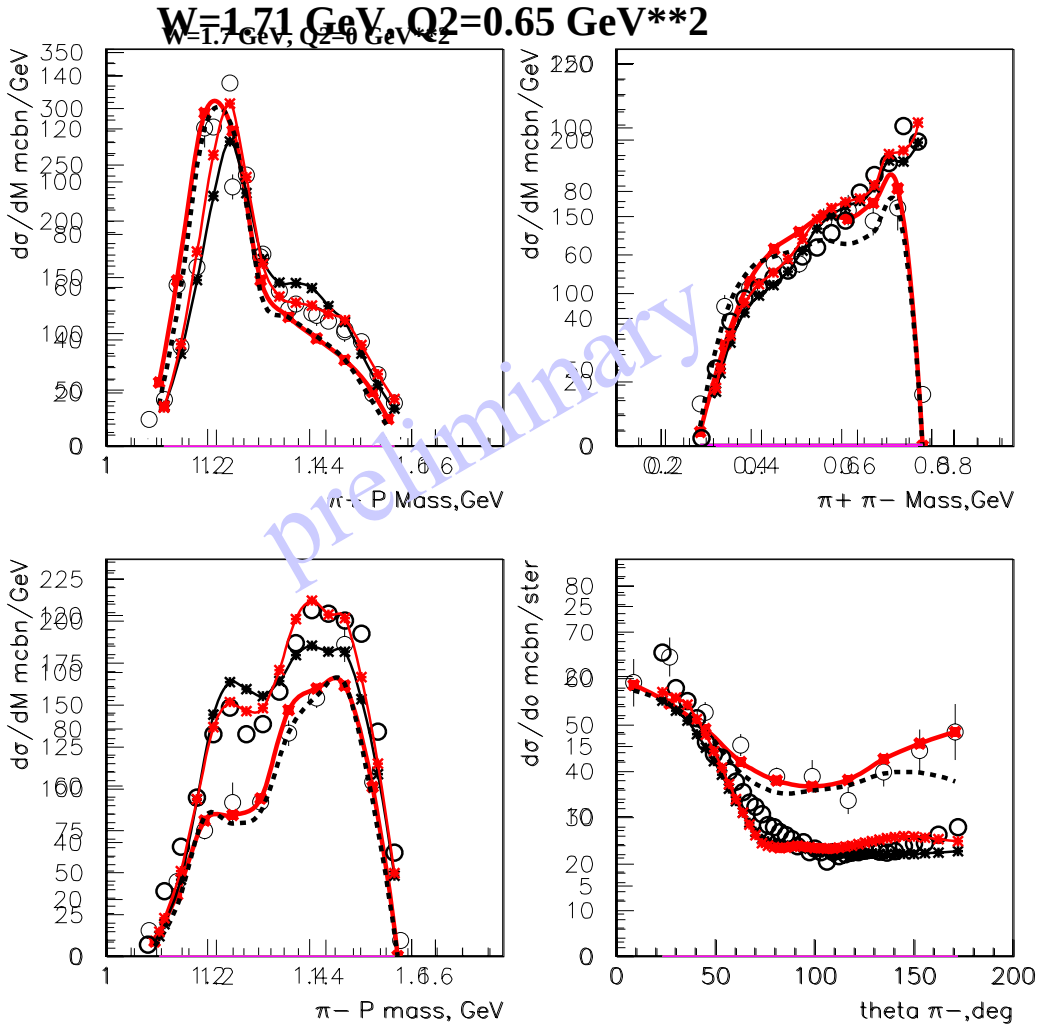
➢ N* contributions are much smaller than non-resonant mechanisms

➢ Full JM05 calculation with and without a new $3/2^+(1720)$ state

Combined Analysis of $\gamma^{(*)}p \rightarrow p\pi^+\pi^-$

— Fit with 3/2+(1720)

— Fit without $3/2^+(1720)$, only variation of electromagnetic and $\pi\Delta$ ρP hadronic couplings and masses of P13(1720), P33(1600)



P13(1720) branching fraction for ρp extracted by a the fit within the JM05 model (without $3/2^+(1720)$)

Q^2	0.00 GeV^2	0.65 GeV^2
BF(ρp)	63%±25%	20%±10%

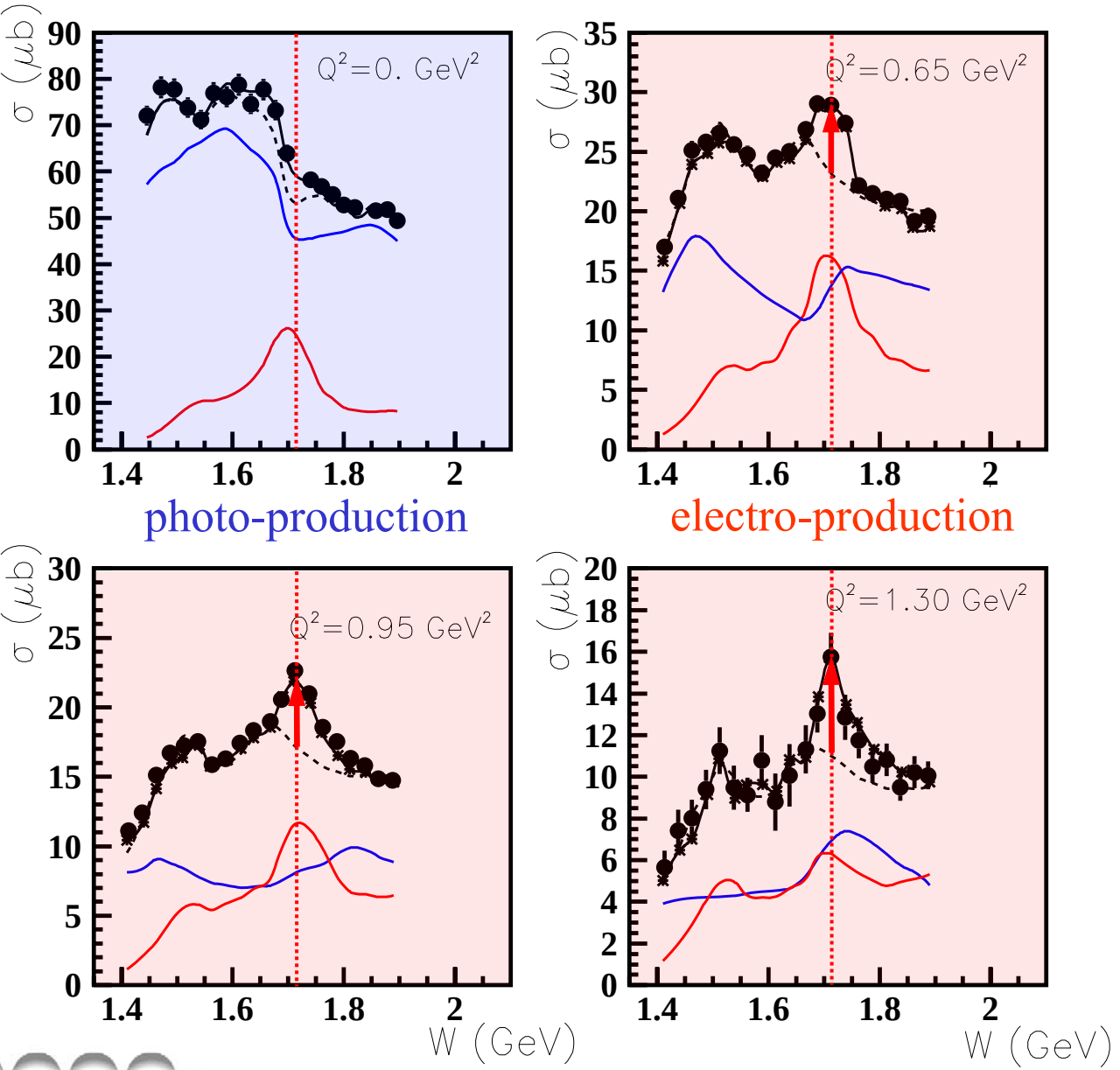
Discrepancy

Preliminary real (M. Bellis) and published (M. Ripani) virtual photon data, combined fit needs both the candidate $3/2^+(1720)$ and the $P_{13}(1720)$ state

Resonances and Background in $\gamma^{(*)}p \rightarrow p\pi^+\pi^-$

CLAS

JM05



Background

Resonances

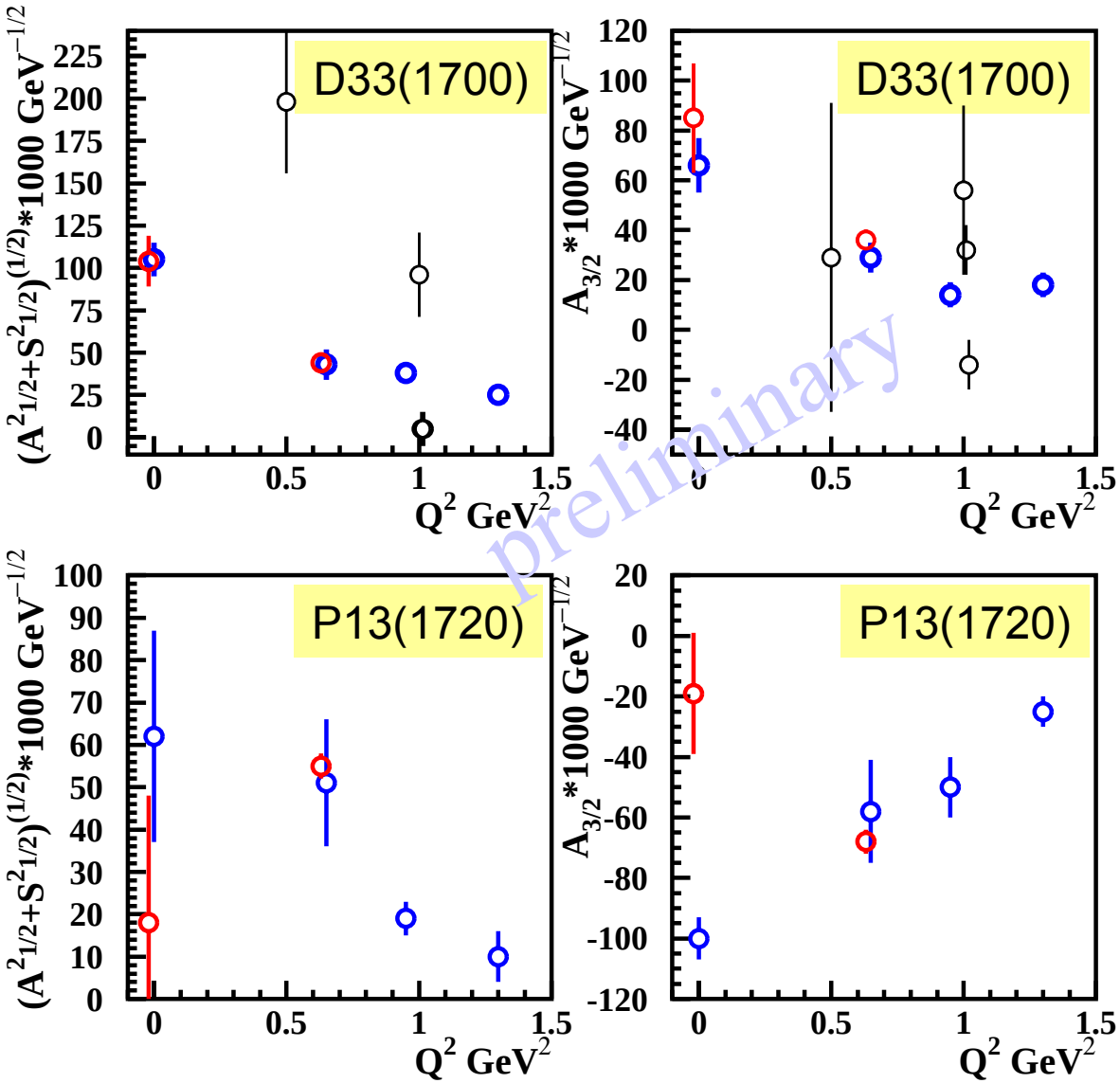
Full JM05

no $3/2^+$

$3/2^+(1720)$
$P_{?3}(1720)$

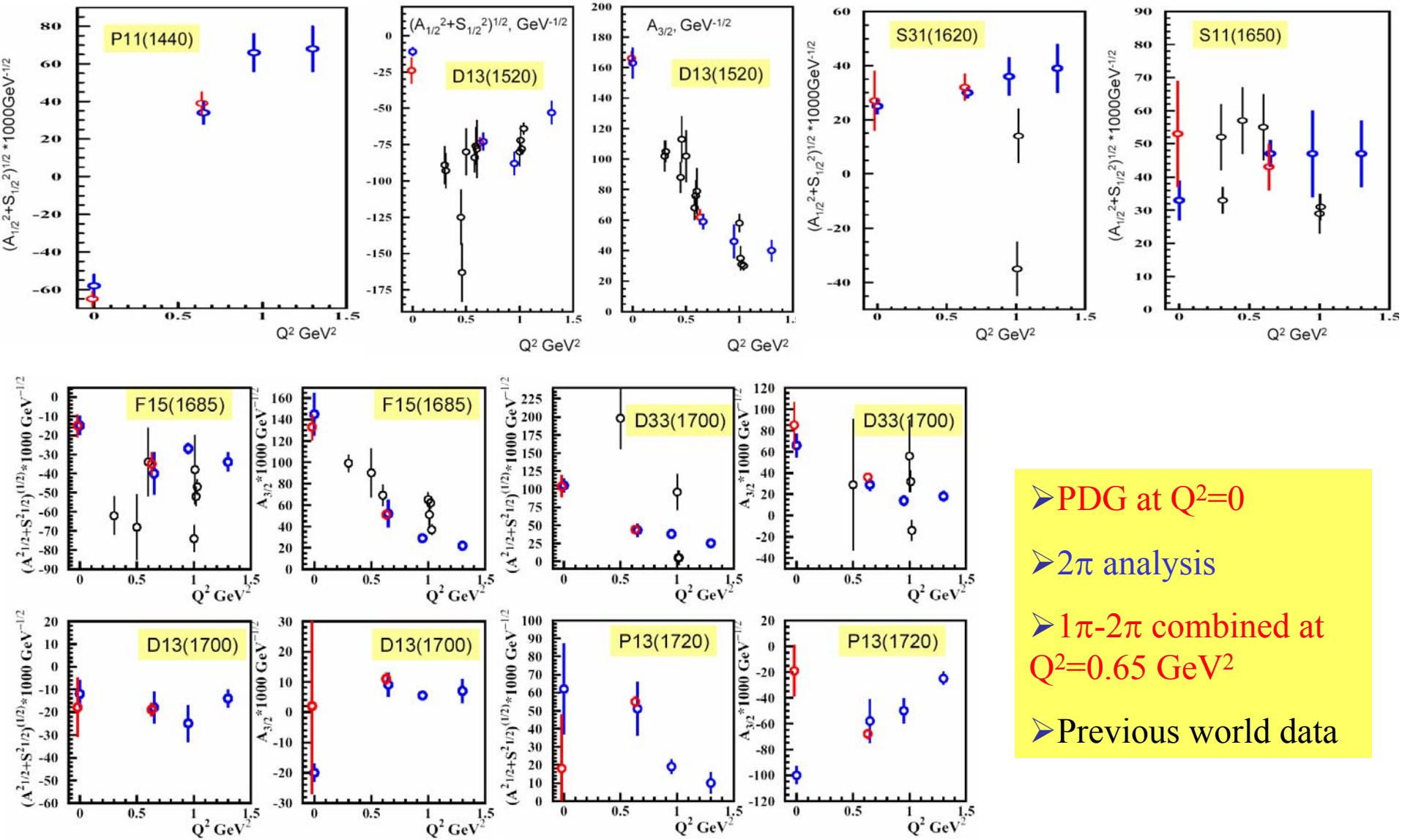
Combined 1π-2π Analysis of CLAS Data

JM05



- PDG at $Q^2=0$
- Previous world data
- 2π analysis
- 1π-2π combined at $Q^2=0.65$ GeV^2
- Many more examples:
  $P_{11}(1440)$, $D_{13}(1520)$, $S_{31}(1650)$, $S_{11}(1650)$, $F_{15}(1685)$, $D_{13}(1700)$, …
- EBAC at JLab:
  Full coupled channel analysis

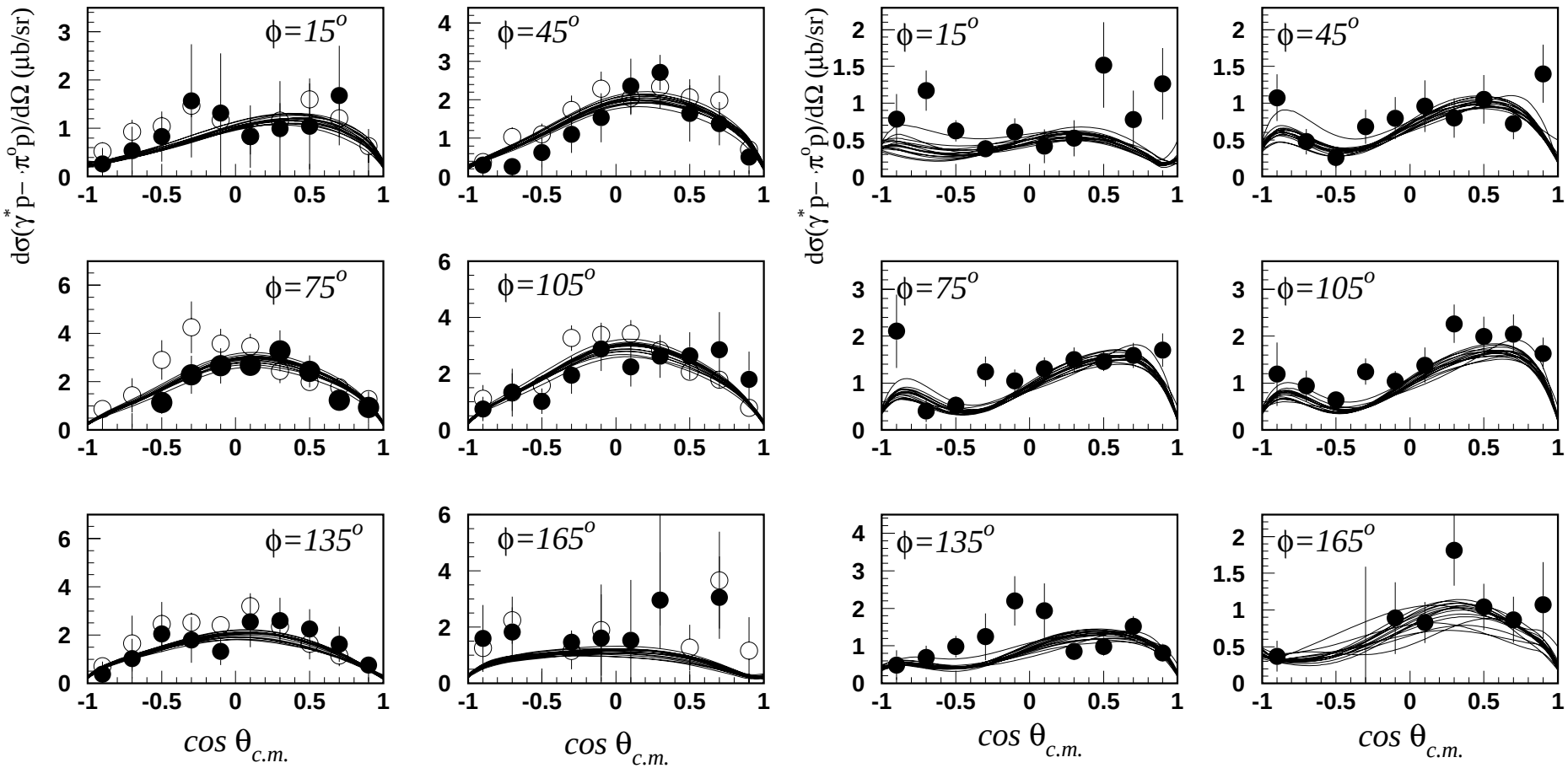
Combined 1π-2π Analysis of CLAS Data



- PDG at $Q^2=0$
- 2π analysis
- 1π-2π combined at $Q^2=0.65$ GeV^2
- Previous world data

1π Data Description by N* Electro-Couplings of the Combined Analysis

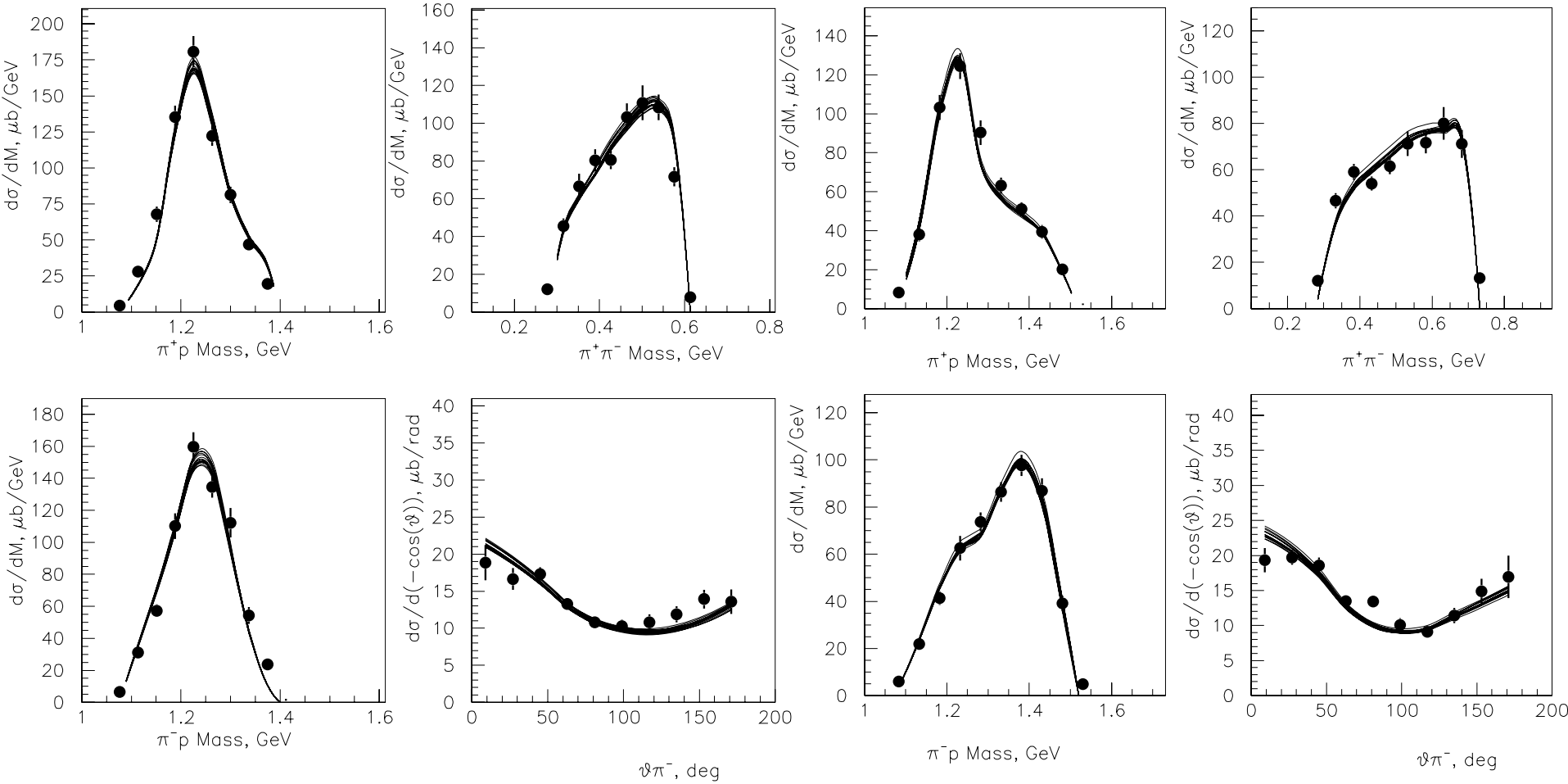
CLAS | W=1.52 GeV Q^2=0.65 GeV^2 | W=1.68 GeV Q^2=0.65 GeV^2 | JM05



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

2π Data Description by N* Electro-Couplings of the Combined Analysis

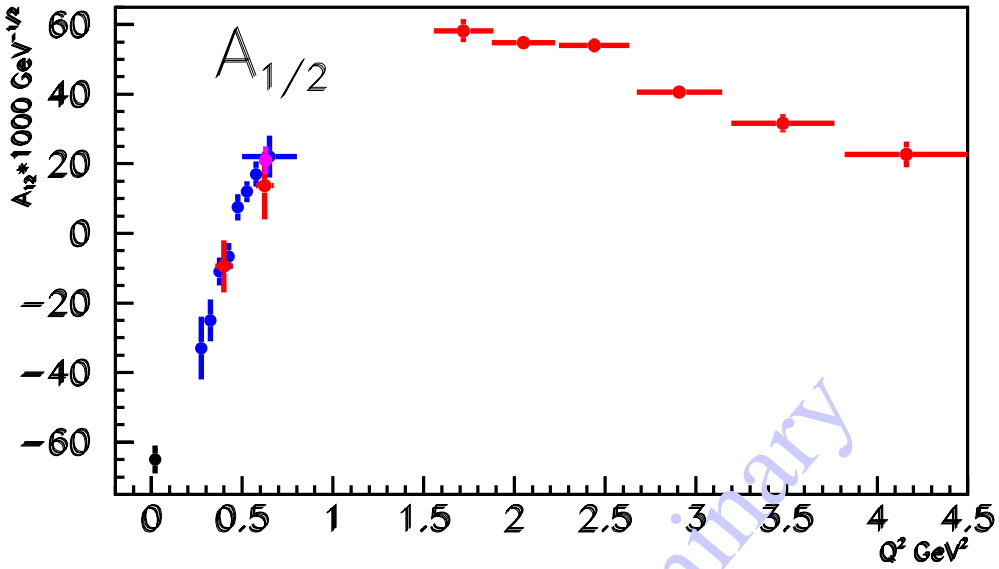
CLAS | W=1.54 GeV Q^2=0.65 GeV^2 | W=1.66 GeV Q^2=0.65 GeV^2 | JM05

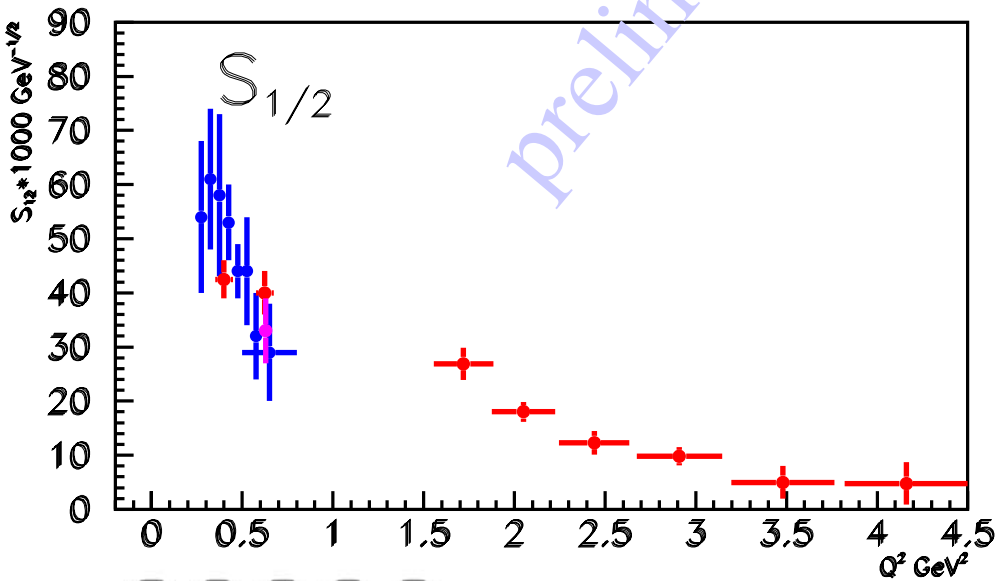


The successful description of all 1π and 2π observables measured with CLAS at Q^2=0.65 GeV^2 demonstrates the credibility of the N* background separation.

Roper Electro-Coupling Amplitudes $A_{1/2}$, $S_{1/2}$

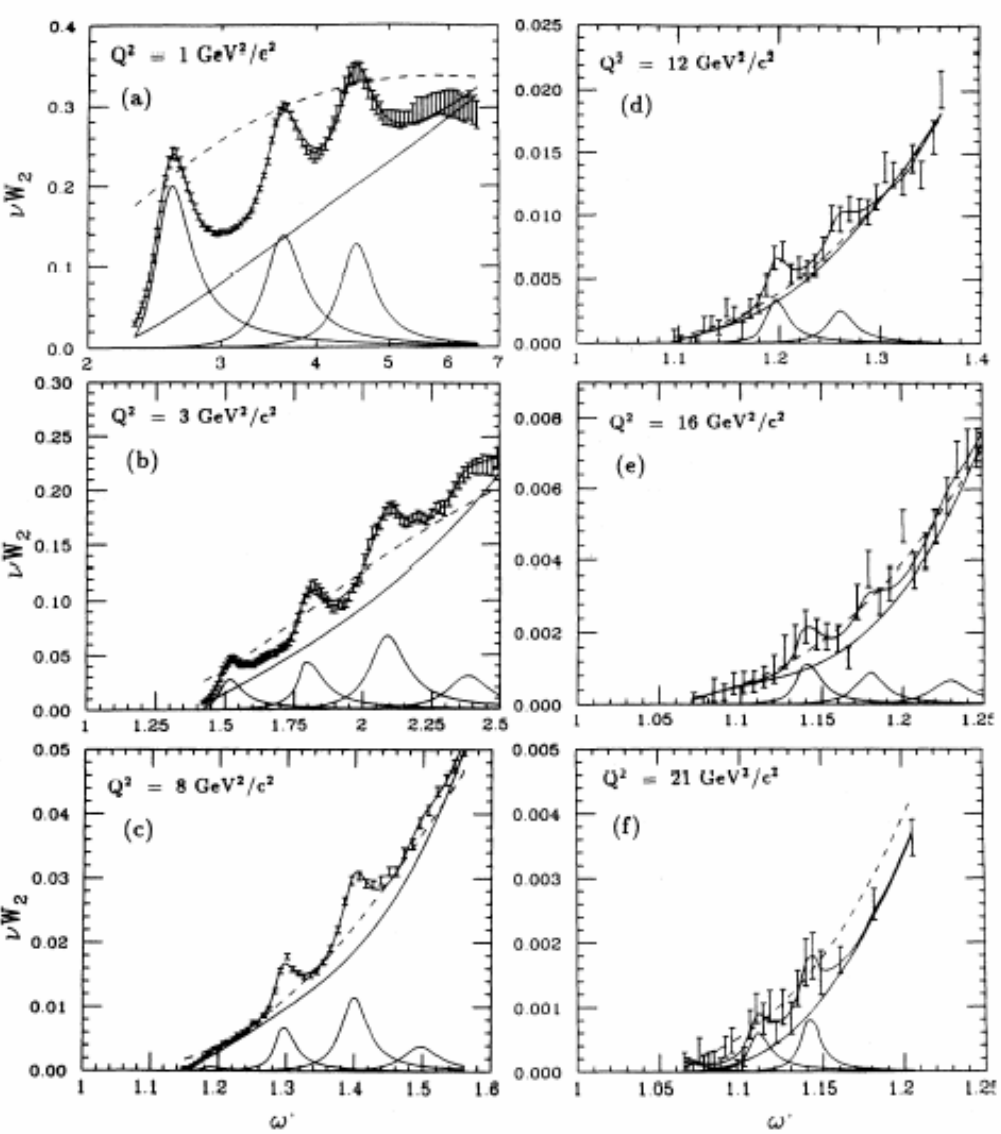
CLAS



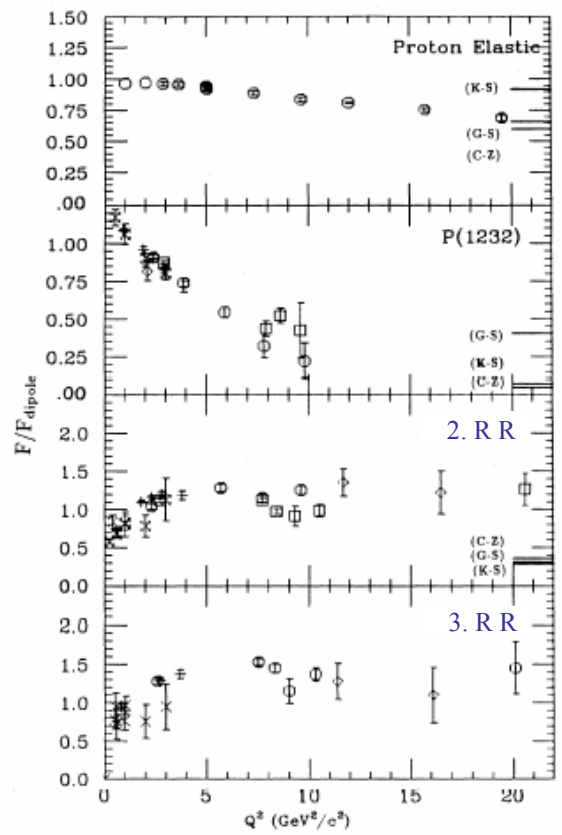


- PDG at $Q^2=0$
- 1π analysis (UIM)
- 1π-2π combined at $Q^2=0.65$ GeV^2
- Newest 2π analysis at low Q^2 (JM 06)

Inclusive Structure Function in the Resonance Region



P. Stoler, PRPLCM 226, 3 (1993) 103-171



Event Generators

- Genova-EG: Dipole Form Factor
- SI-DIS: Deep Inelastic Scattering

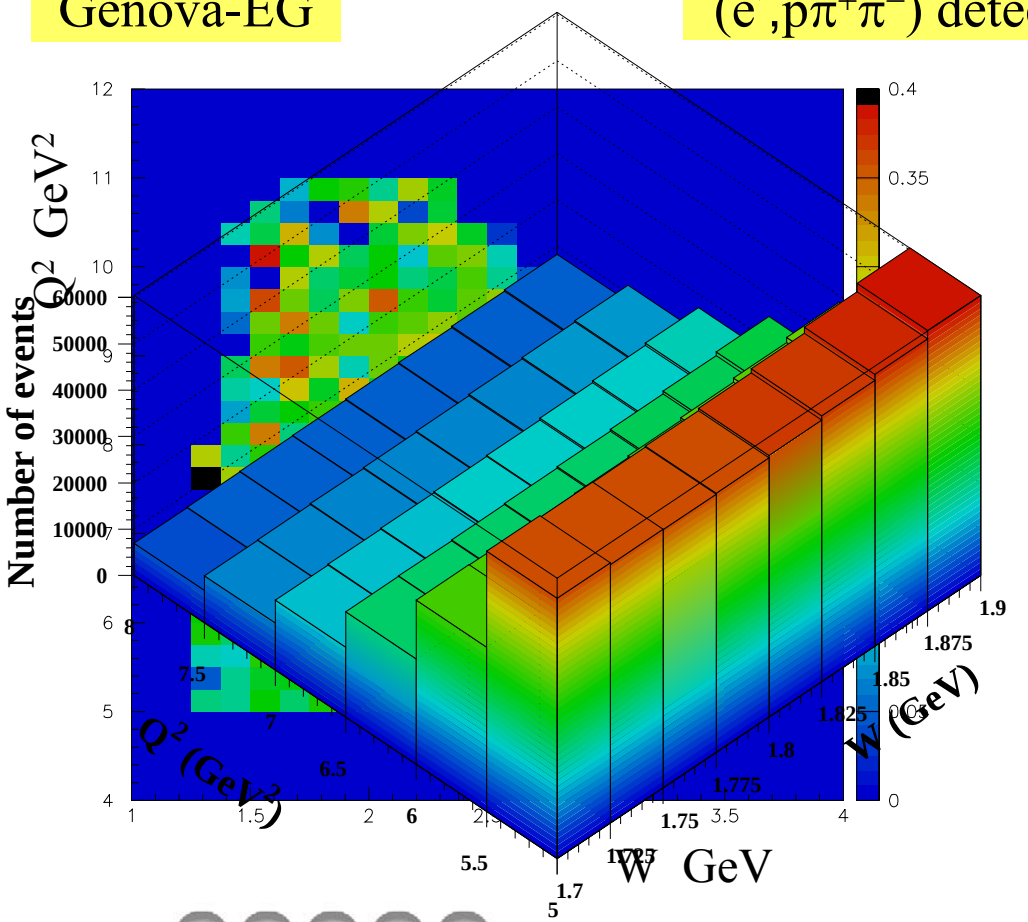
Kinematical Coverage of CLAS12

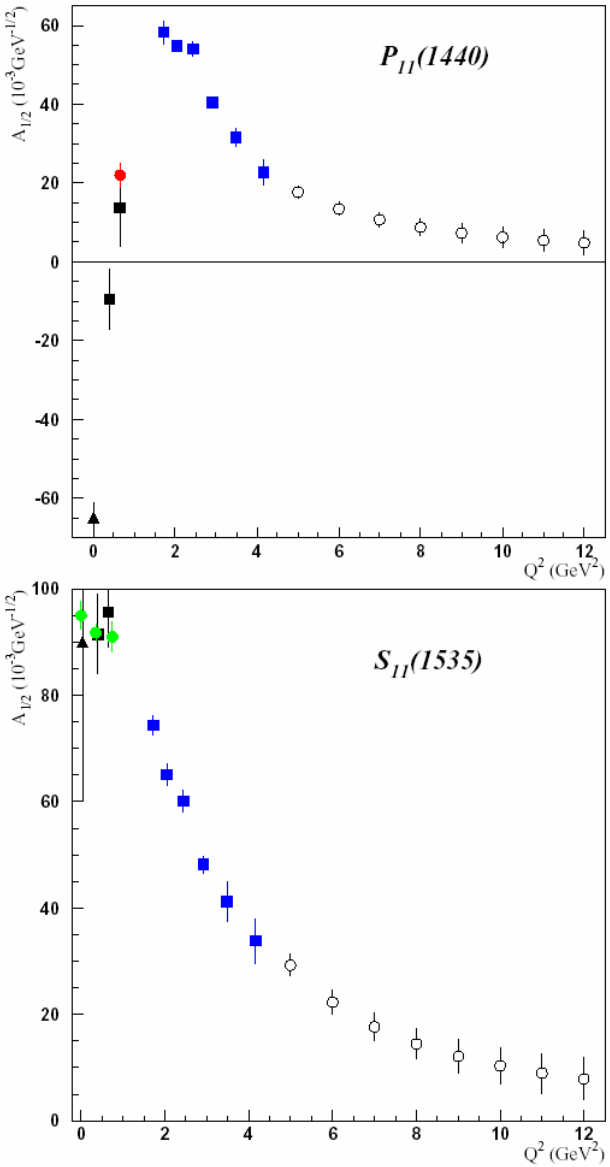
60 days

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

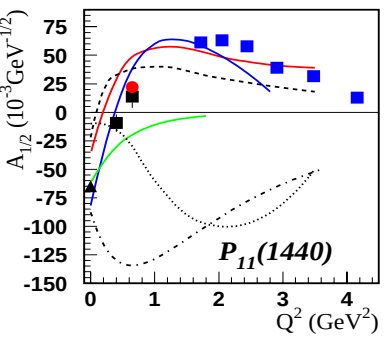
Genova-EG

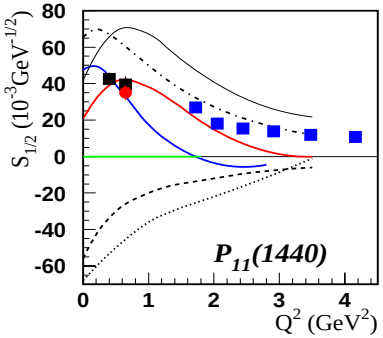
$(e', p\pi^+\pi^-)$ detected

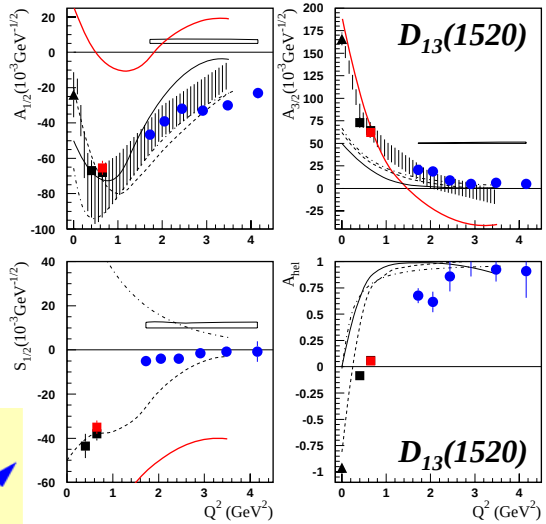


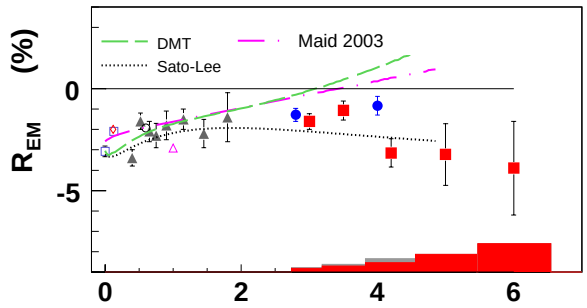


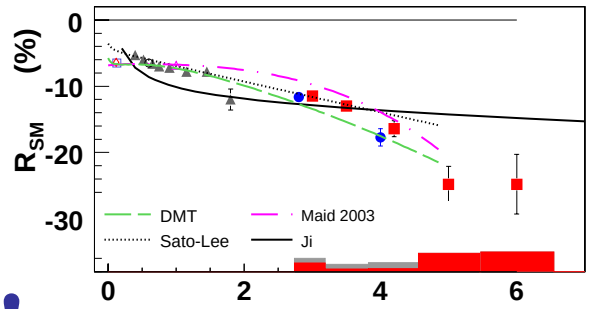
Conclusion: Do Exclusive Electron Scattering



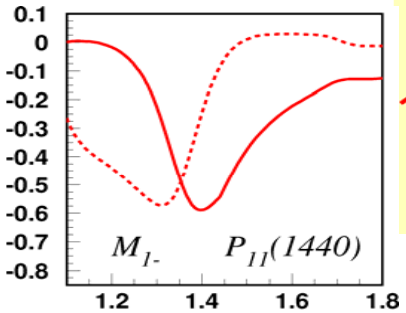


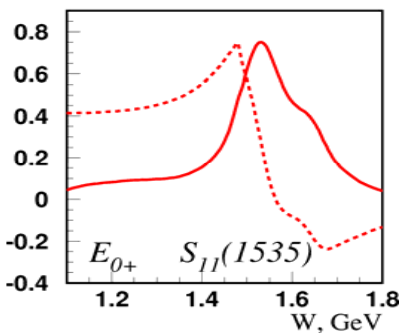


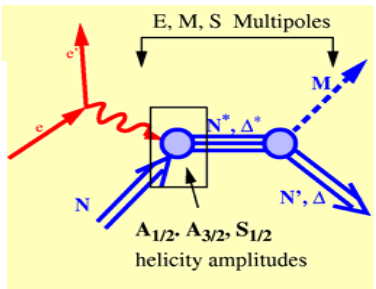




$Q^2 = 2.05$ GeV^2







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Learn QCD!