N* Transition Form Factors with CLAS at Jefferson Lab

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For the CLAS Collaboration

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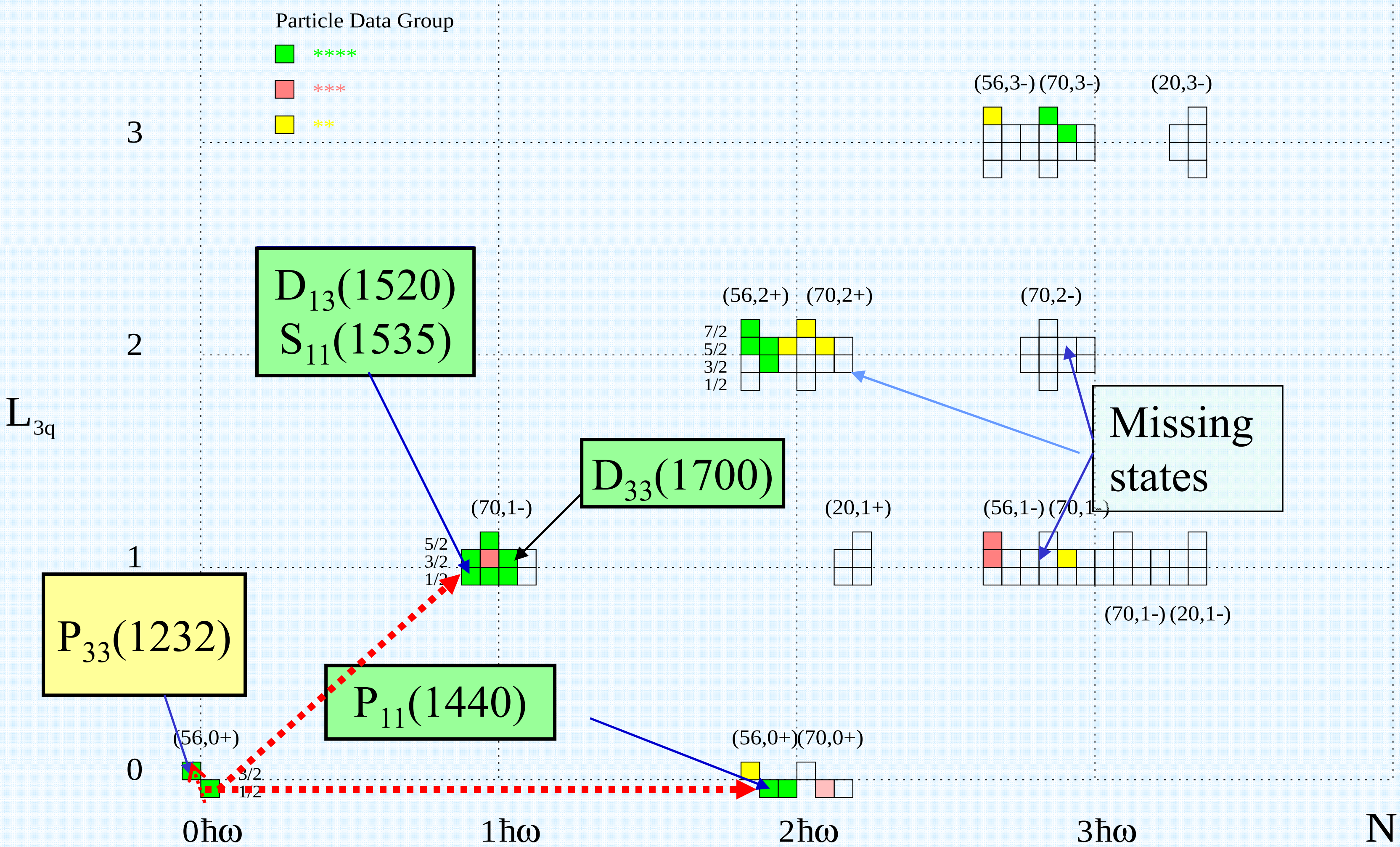
Jefferson Lab

University of Connecticut

The N* spectrum and its Classification

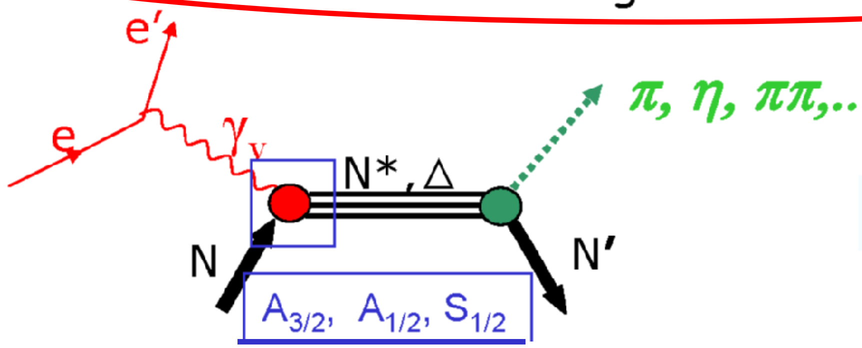
Observed spectrum with supermultiplets → degrees of freedom
→ 3 quarks with SU(6)xO(3) symmetric interactions

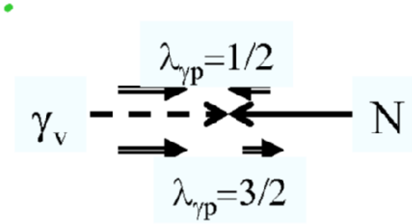


Electromagnetic Excitation of N*'s

The experimental N* Program has two major components:

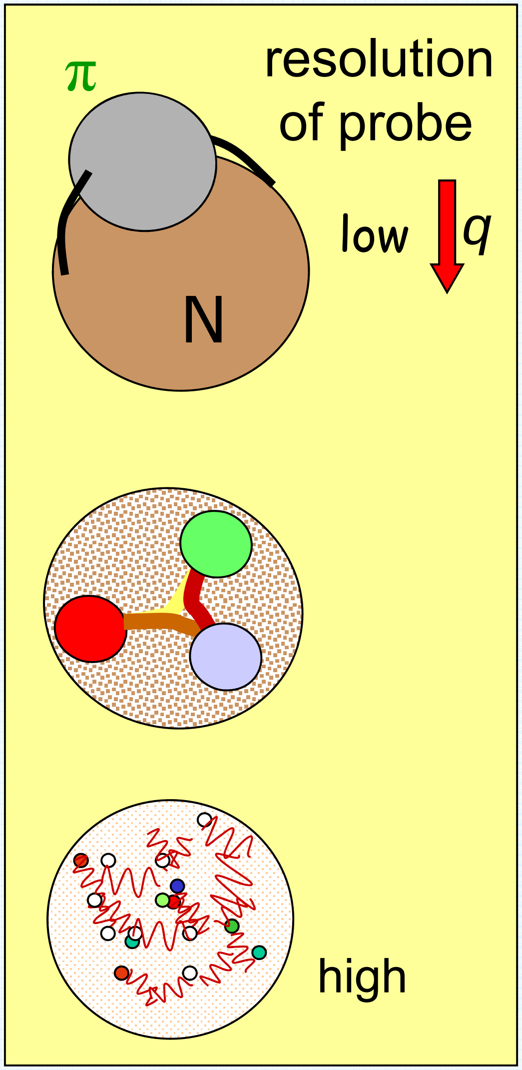
1) Accurate measurements of transition form factors ($A_{3/2}$, $A_{1/2}$, $S_{1/2}$) of known states as photon virtuality (Q^2) to probe their internal structure and confining mechanism





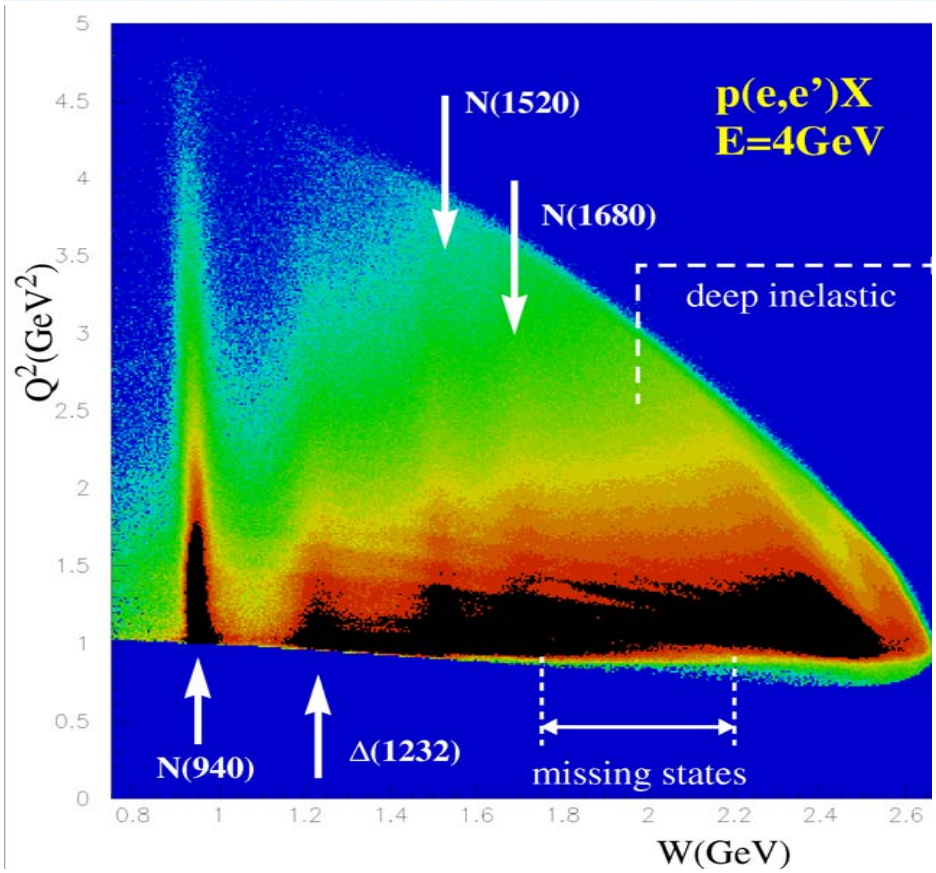
2) Search for undiscovered new baryon states.

Electromagnetic Excitation of N*



- Allows to address the central question:
What are the relevant degrees-of-freedom at varying distance scale?

Electromagnetic Excitation of N*'s

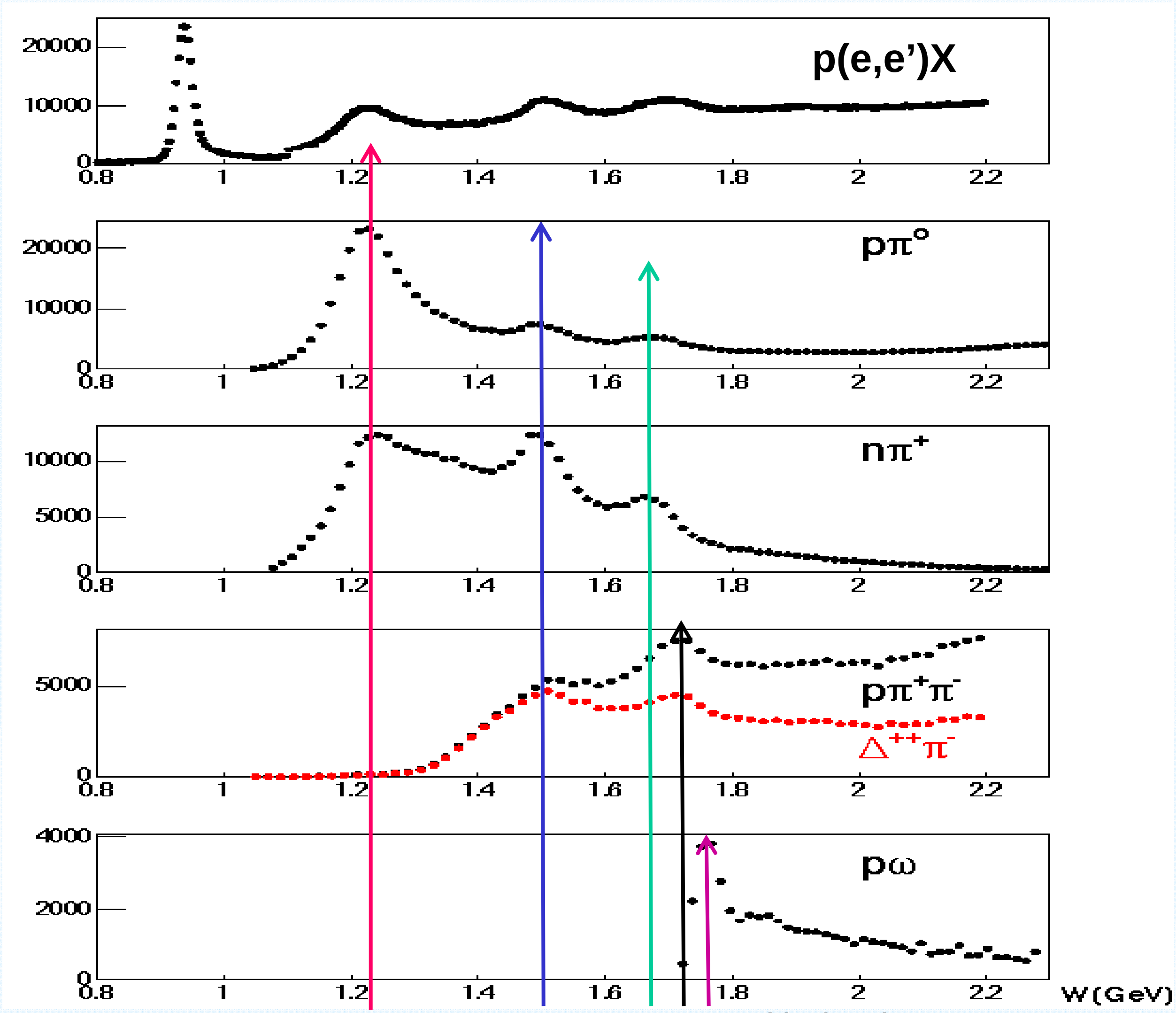


1. Measure different exclusive processes

2. Measure polarization observables

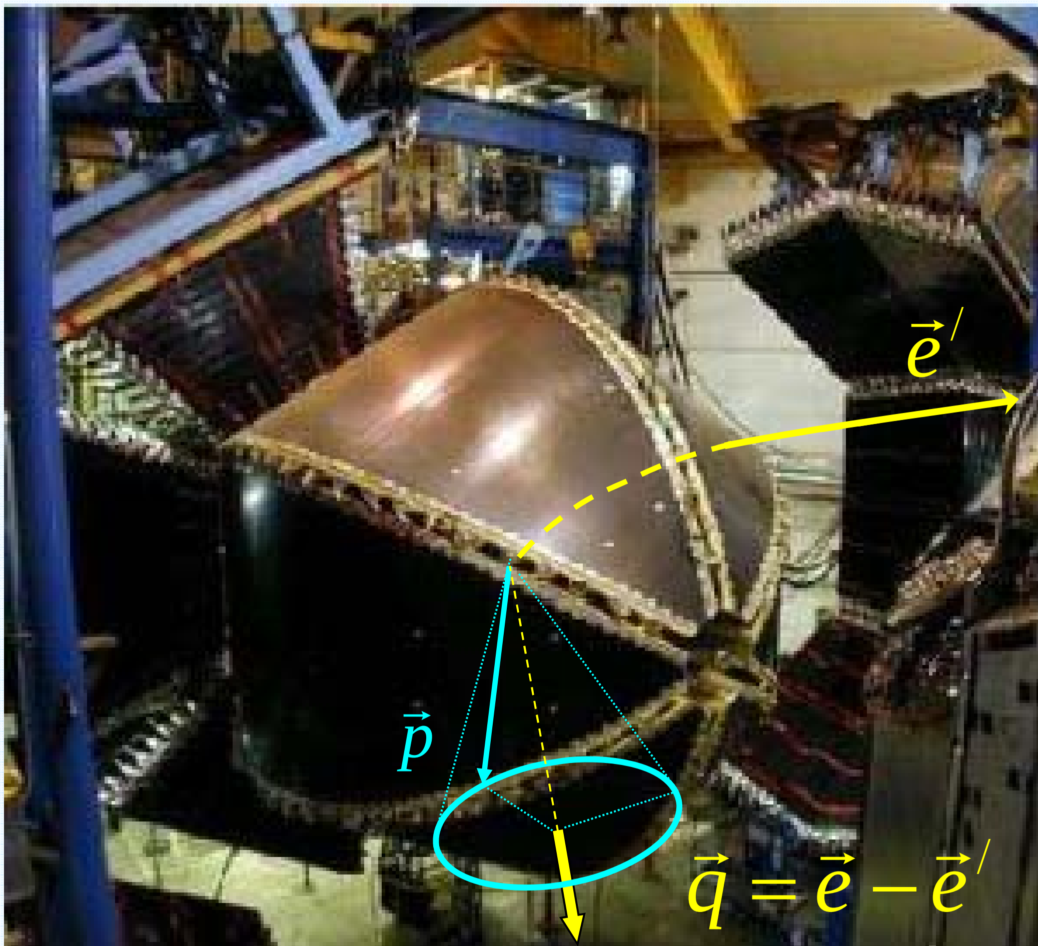
CLAS

Exclusive Processes in N* Studies

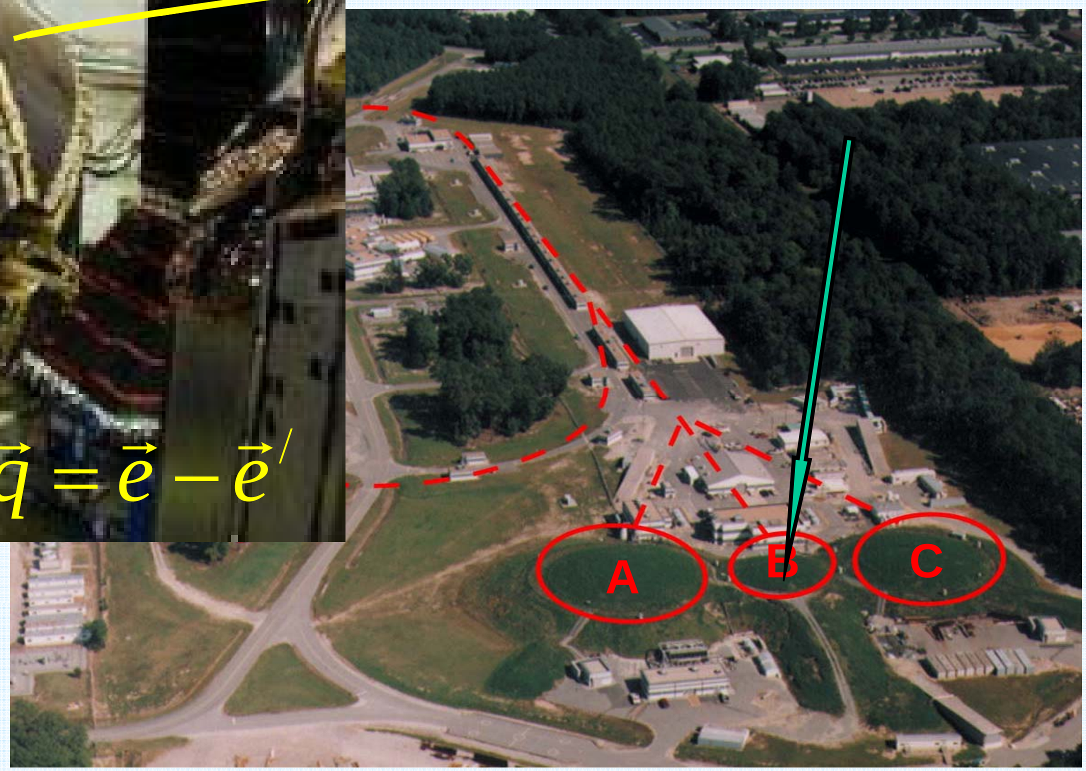


Hadronic mass

CEBAF at Jefferson Lab and CLAS



E_{max} ~ 6 GeV
I_{max} ~ 200 μA
Duty Factor ~ 100%
σ_E/E ~ 2.5 10^{-5}
Beam P ~ 80%
E_{γ_0}(tagged) ~ 0.8- 5.5 GeV

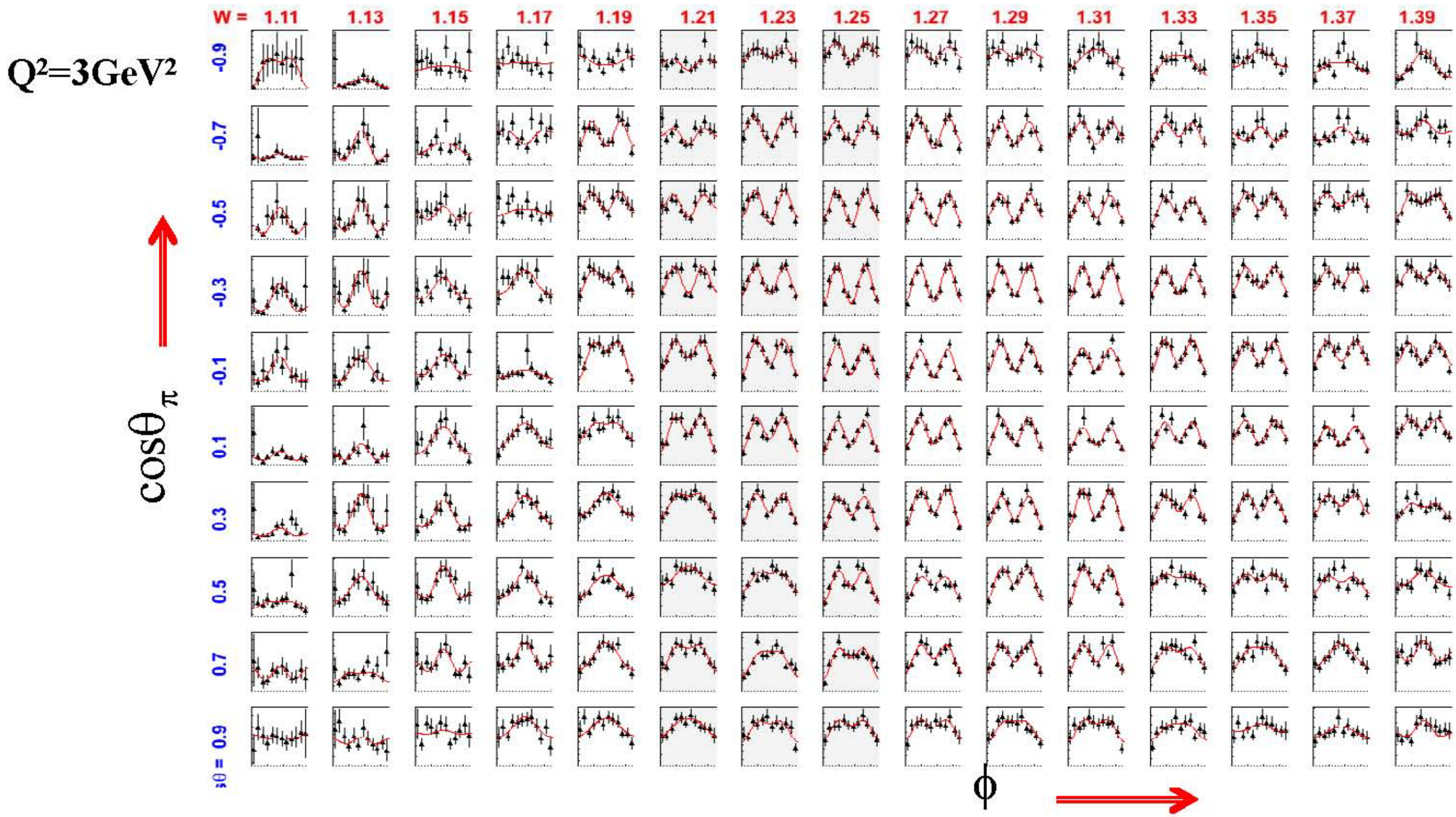


Electroproduction data and analyses from CLAS

Reaction	W (GeV)	Q^2 (GeV^2)	Observable	Physics extracted
$ep \to ep\pi^0$	1.1 - 1.4	0.4 - 1.8; 3 - 6	$\sigma_T+\varepsilon_L\sigma_L$, σ_{TT}, σ_{LT}; $d\sigma/d\Omega$	Δ (G_M, R_{EM}, R_{SM})
$\vec{e}p \to ep\pi^0$	1.1 - 1.4	0.4 - 0.65	$\sigma_{LT'}$	Δ (G_M, R_{EM}, R_{SM})
$\vec{e}\vec{p} \to ep\pi^0$	1.1 - 1.4; 1.1 - 1.7	0.5 - 1.5; 0.19 - 0.77	A_t , A_{et}	Comparison to models
$ep \to en\pi^+$	1.1 - 1.6	0.25 - 0.65	$\sigma_T+\varepsilon_L\sigma_L$, σ_{TT}, σ_{LT}	$P_{11}(1440)$ ($A_{1/2}$, $S_{1/2}$), $D_{13}(1520)$ ($A_{1/2}$, $A_{3/2}$, $S_{1/2}$), S_{11} (1535) ($A_{1/2}$, $S_{1/2}$)
$\vec{e}p \to en\pi^+$	1.3 - 1.5; 1.15 - 1.7	0.4 - 0.65; 1.72 - 4.16	$\sigma_{LT'}$; $\sigma_T+\varepsilon_L\sigma_L$, σ_{TT}, σ_{LT} , $\sigma_{LT'}$	$P_{11}(1440)$ ($A_{1/2}$, $S_{1/2}$), $D_{13}(1520)$ ($A_{1/2}$, $A_{3/2}$, $S_{1/2}$), S_{11} (1535) ($A_{1/2}$, $S_{1/2}$)
$\vec{e}\vec{p} \to en\pi^+$	1.12 - 1.84	0.35 - 1.5	$(A_1 + \eta A_2)/(1+\varepsilon R)$	Comparison to models
$ep \to ep\eta$	1.5 - 1.86	0.25 - 1.5	σ, $d\sigma/d\Omega$ → Legendre coeff. in $\sigma_T+\varepsilon_L\sigma_L$, σ_{TT}, σ_{LT}	S_{11} (1535) ($A_{1/2}$, $S_{1/2}$)
$ep \to ep\eta$	1.5 - 2.3	0.13 - 3.3	σ, $d\sigma/d\Omega$ → Legendre coeff. in $\sigma_T+\varepsilon_L\sigma_L$, σ_{TT}, σ_{LT} + σ_{TT}/σ, σ_{LT}/σ	S_{11} (1535) ($A_{1/2}$, $S_{1/2}$) + further PWA
$e p \to ep\pi^+\pi^-$	1.4 - 2.1; 1.3 - 1.57	0.5 - 1.5; 0.2 - 0.6	Simultaneous fit of $d\sigma/d\theta$ and $d\sigma/dM$	$P_{11}(1440)$, $D_{13}(1520)$, $P_{13}(1720)$, $D_{33}(1700)$
$\vec{e} p \to eK^+\vec{\Lambda}$	1.6 - 2.15	0.3 - 1.5	Λ transferred pol. $P'_{x'}$, $P'_{z'}$	Comparison to models
$ep \to eK^+\Lambda$, $K^+\Sigma^0$	1.6 - 2.4	0.5 - 2.8	σ_T , σ_L, σ_{TT}, σ_{LT}	Comparison to models
$\vec{e} p \to eK^+\Lambda$	1.65 - 2.05	0.65, 1	$\sigma_{LT'}$	Comparison to models

CLAS π^0 electroproduction data

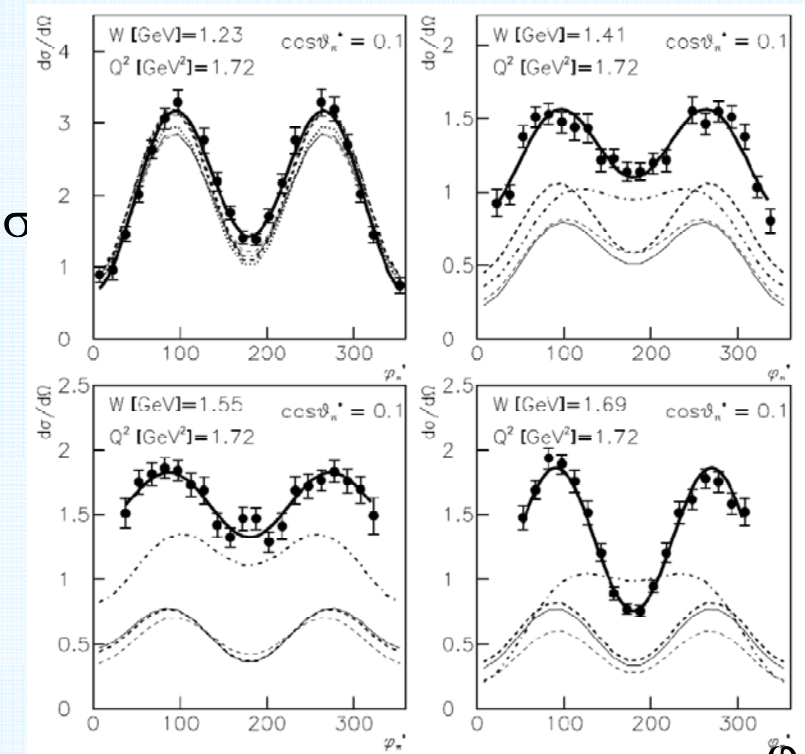
Complete angular distributions in Θ_π and ϕ_π, in wide W & Q^2 range.



CLAS π^+ electroproduction data

$$\frac{d\sigma}{d\Omega^{lab}dE'd\Omega_\pi^{CM}} = \Gamma_v\left(\sigma_T + \varepsilon_L\sigma_L + \varepsilon\sigma_{TT}\cos 2\phi + \sqrt{2\varepsilon_L(1+\varepsilon)}\,\sigma_{LT}\cos\phi + h\sqrt{2\varepsilon_L(1-\varepsilon)}\,\sigma'_{LT}\sin\phi\right)$$

dσ

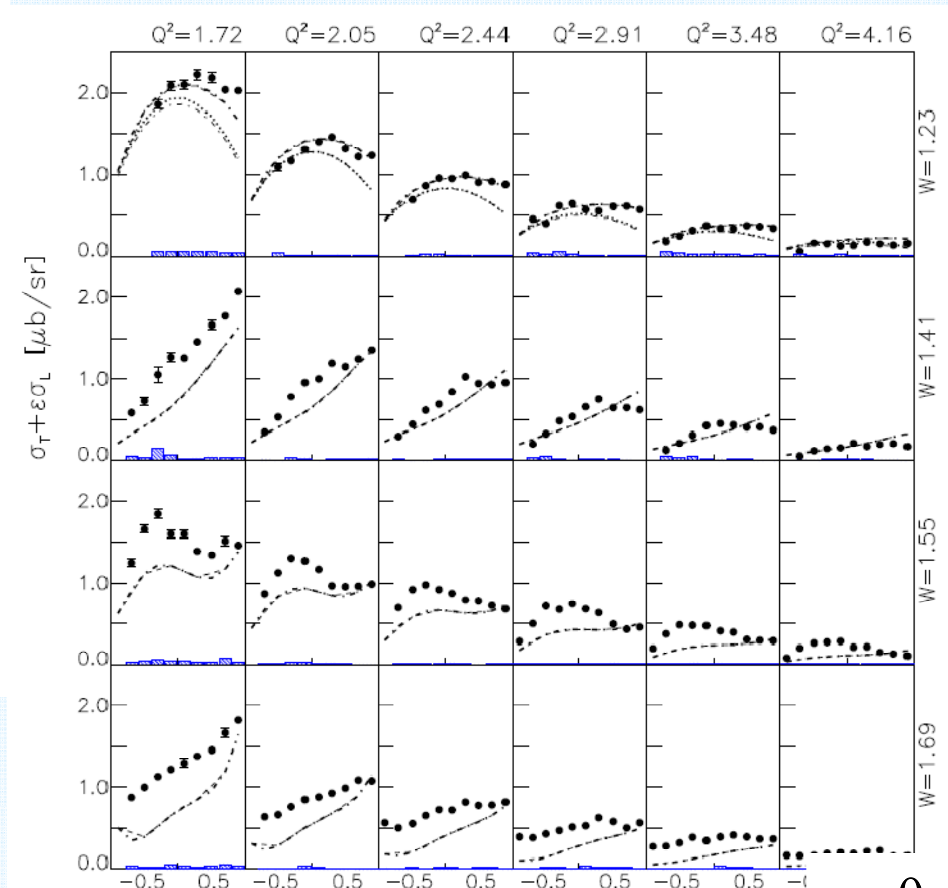


ϕ

Bold solid line: UIM fit

MAID00 (thin dashed), MAID03 (bold dash-dotted),
Sato-Lee (bold dotted), Sato-Lee04 (thin dash-dotted)

$\sigma_T+\varepsilon\sigma_L(\mu b/sr)$

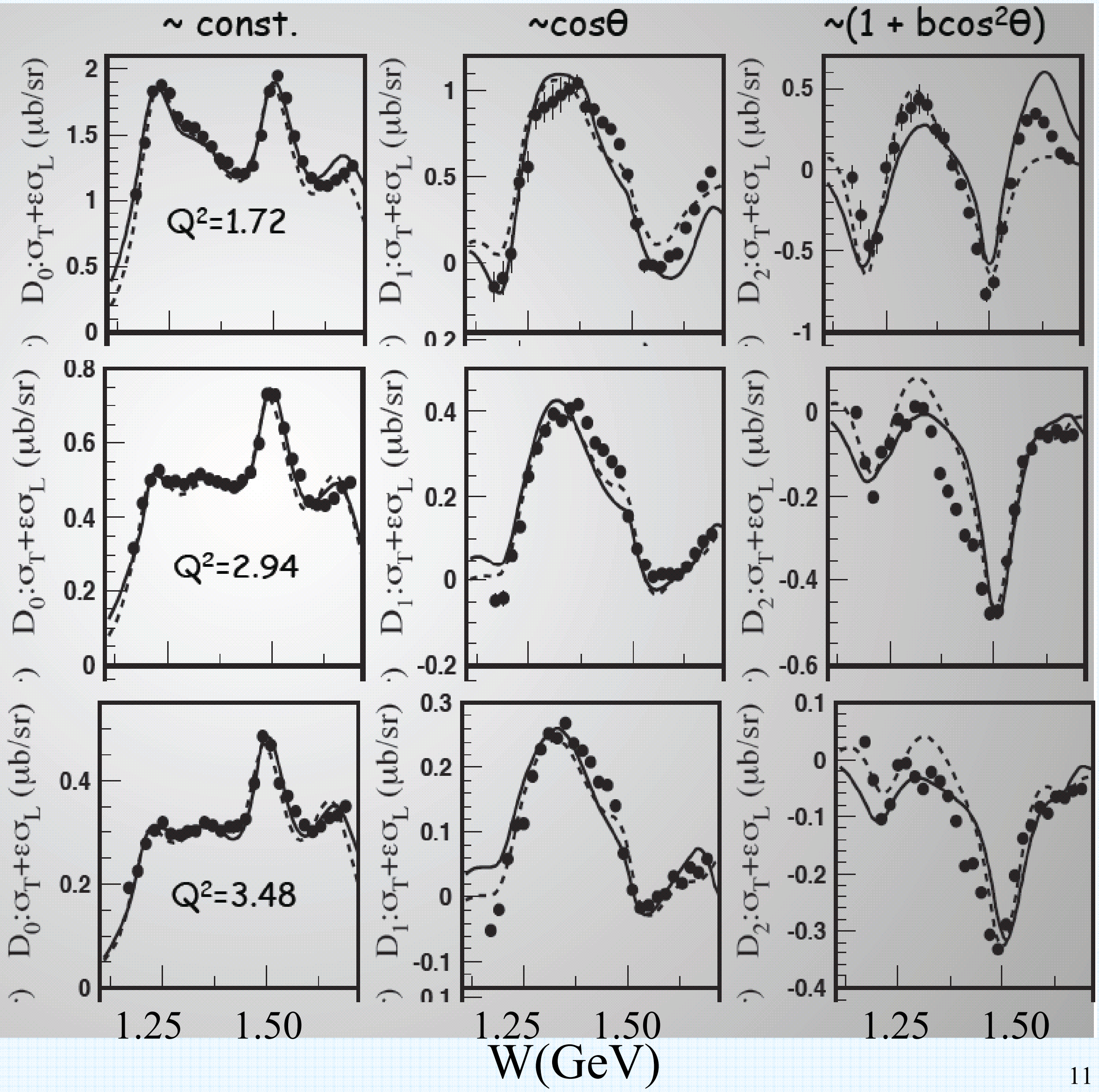


$\cos\theta_\pi$

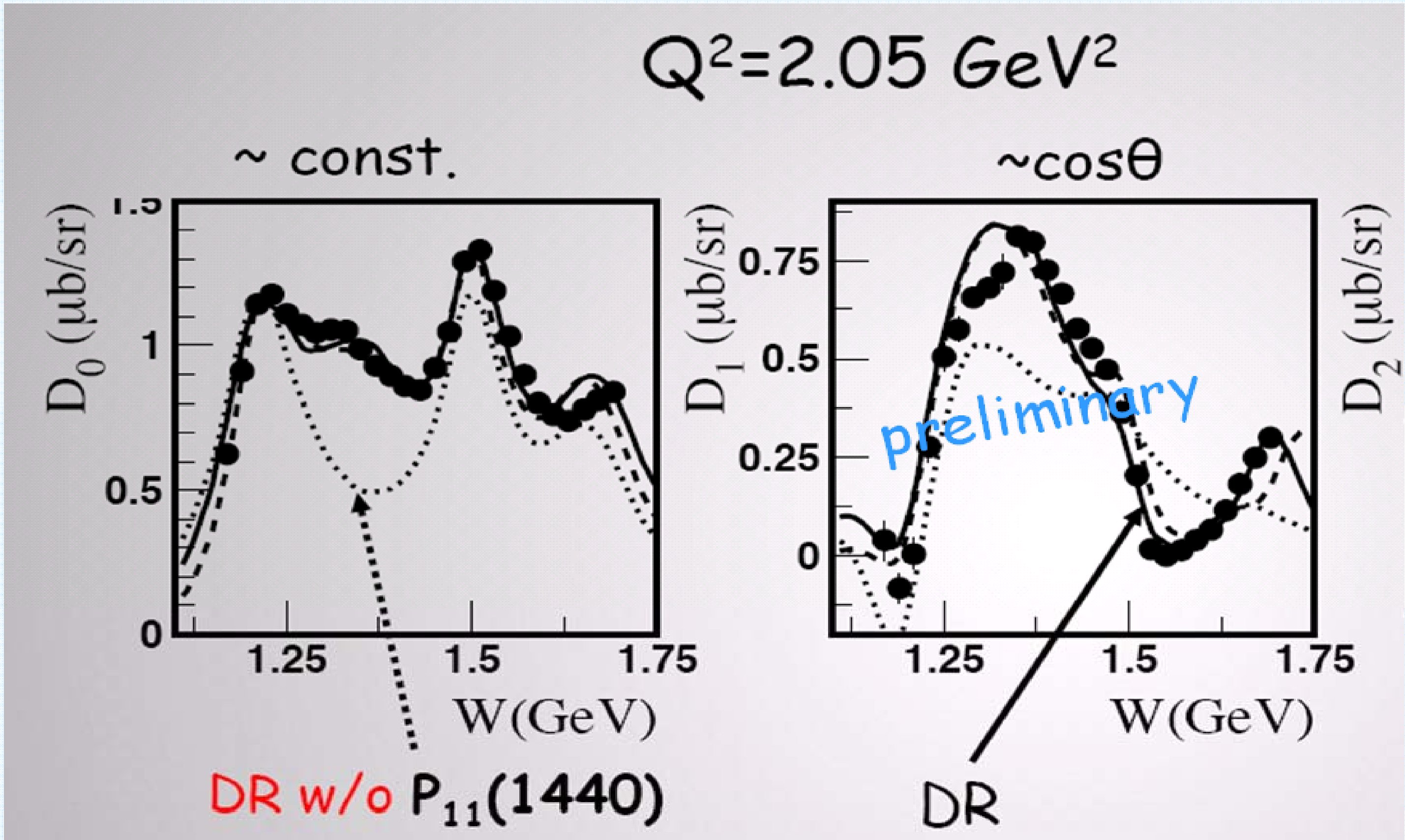
Legendre Moments of $\sigma_T + \varepsilon\sigma_L$

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

Delta disappears rapidly with Q^2, other structures and features remain strong.



$P_{11}(1440)$ contributions to Leg. Mom. of $\sigma_T + \varepsilon\sigma_L$



Peaks in Δ, D_{13}/S_{11} region, broad enhancement from P_{11}

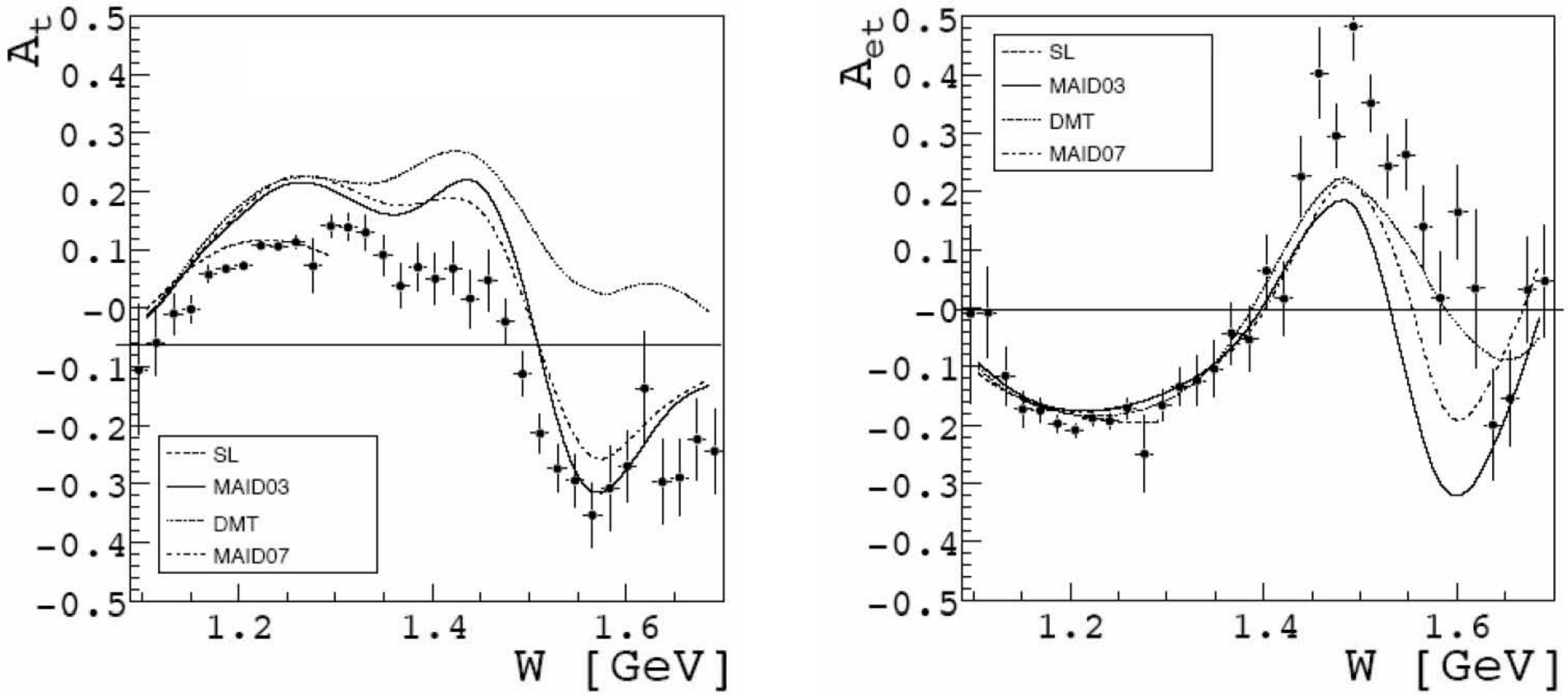
Broad structure from 1.2 to 1.5GeV due to s-p interference terms.

Integrated Target and Beam-Target Asymmetries

CLAS

$\vec{e}\,\vec{p} \rightarrow e'p\pi^0$

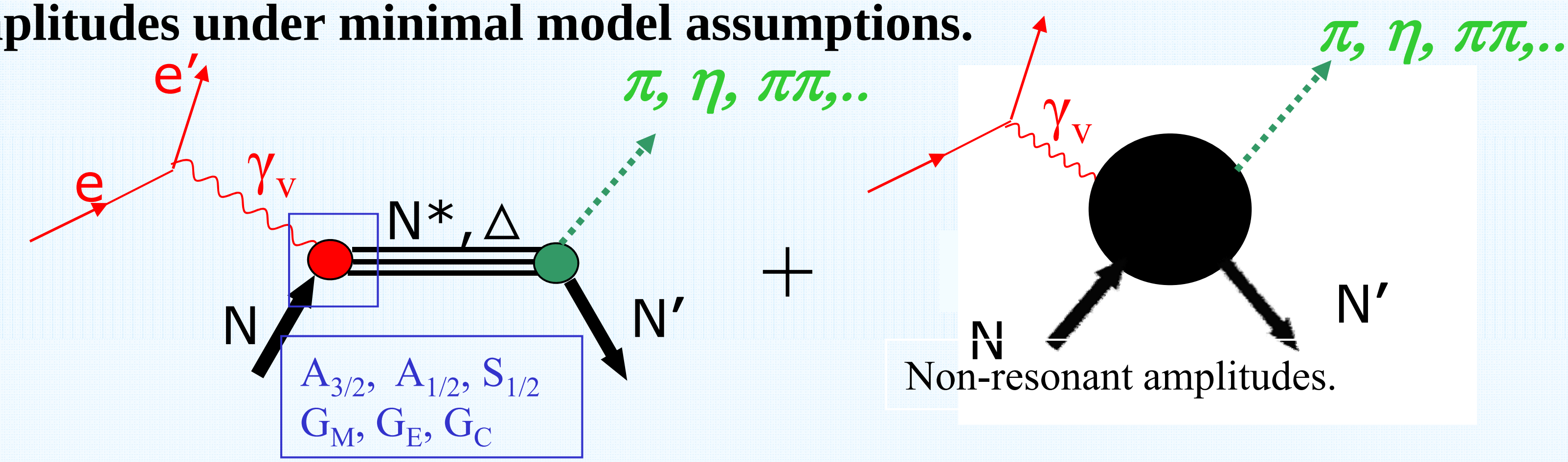
A. Biselli



The asymmetries are integrated over θ^* and φ^* in the Q^2 range from 0.187 to 0.770 GeV^2 and will further reduce the model dependence of the extracted resonance parameters.

How N* electrocouplings can be accessed

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



Used Dispersion relations (DR) and Unitary Isobar Model (UIM) Fits

14
14

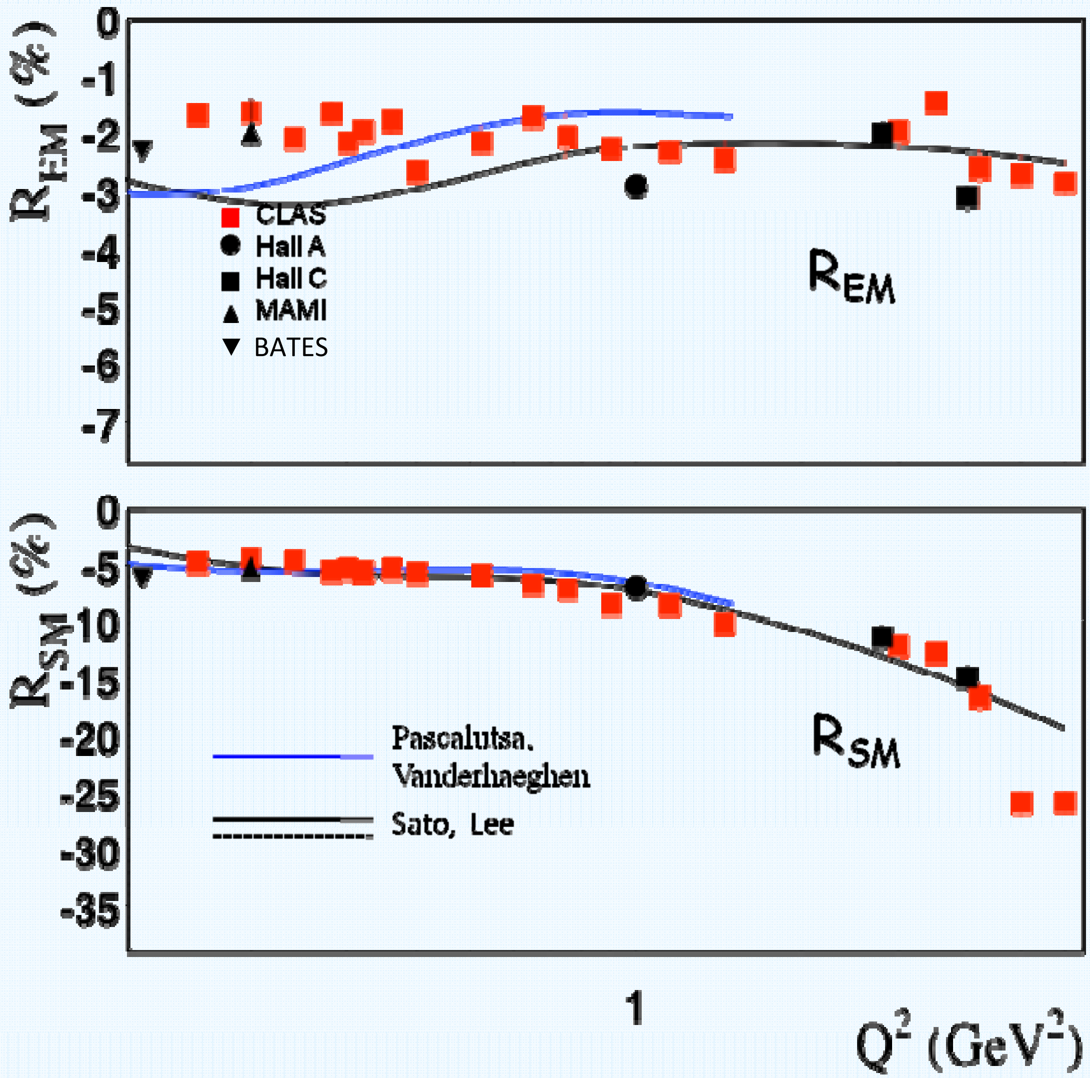
$\gamma^* p \rightarrow \Delta(1232)\ P_{33}(1232)$: R_{EM} and R_{SM}

$$R_{EM} = E_{1+}/M_{1+}$$
$$R_{SM} = S_{1+}/M_{1+}$$

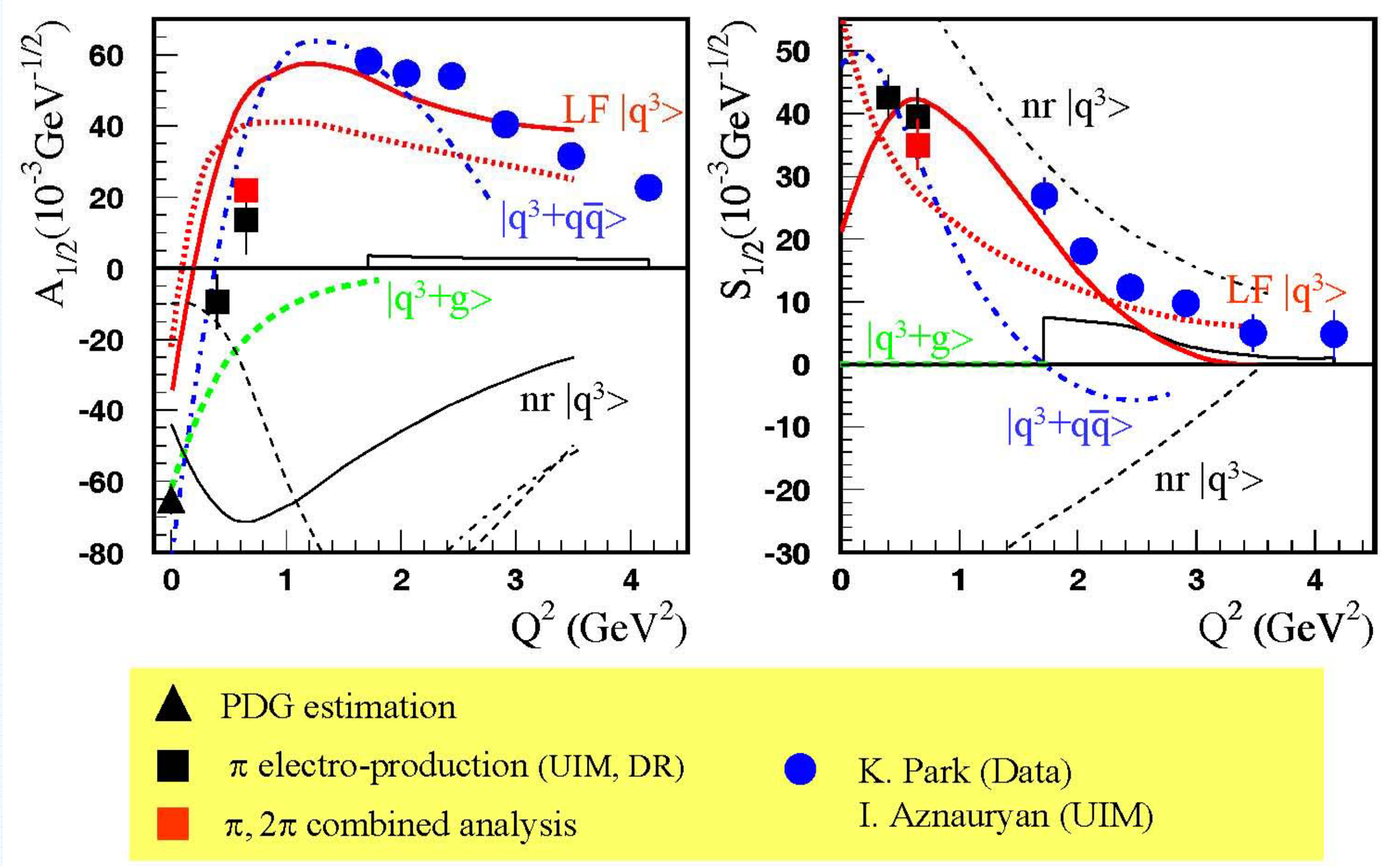
- ✓ $R_{EM} < 0$ favors oblate shape of the Δ, prolate shape of the nucleon at large distances
- ✓ Scattering off massless fermions: Helicity is conserved, thus
- ✓ $A_{3/2} = 0$ ➔
  $R_{EM} \rightarrow 1$, $R_{SM} \rightarrow$ const

We are still far from pQCD asymptotia

(not shown here)
LQCD calculations:
encouraging, work in progress…

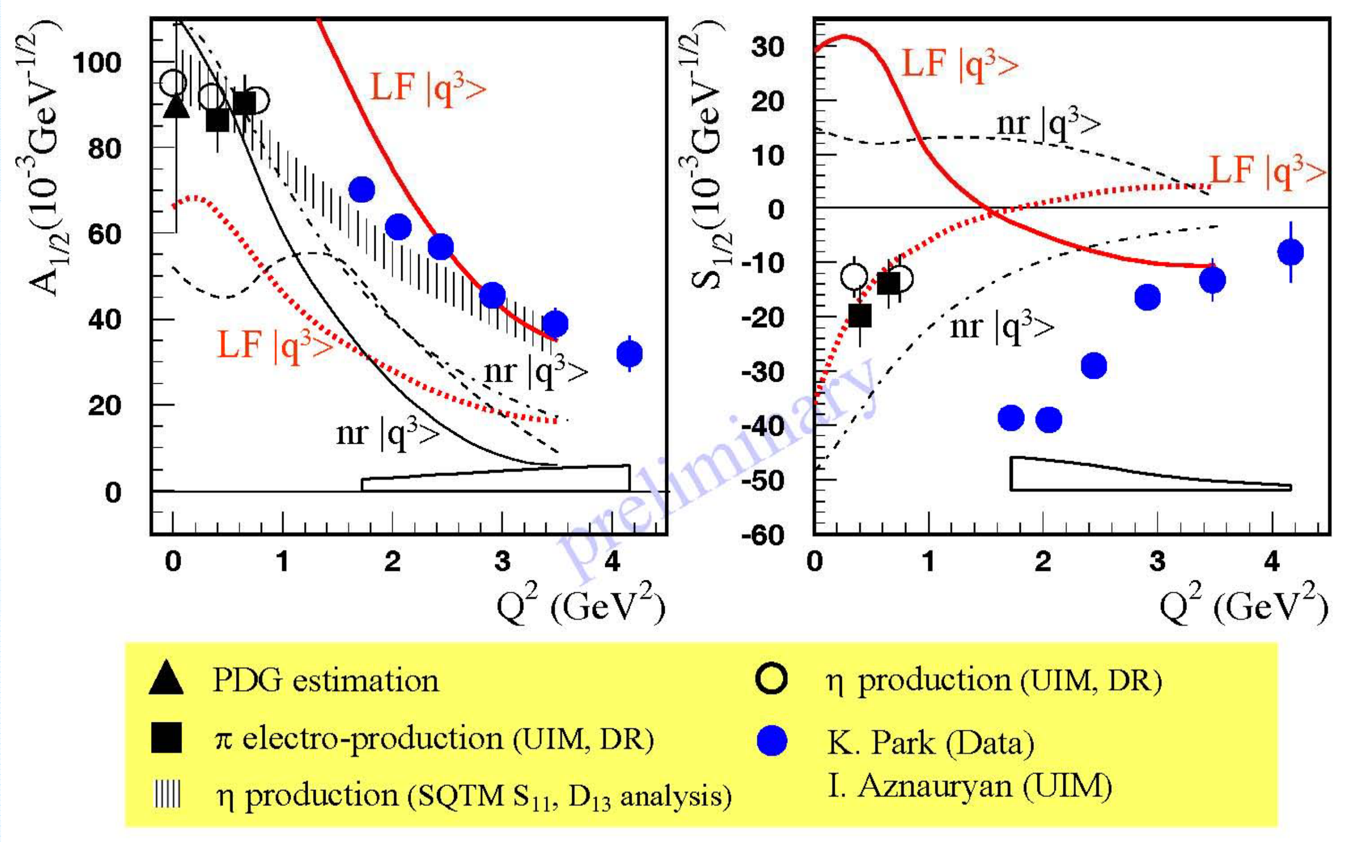


$\gamma^* p \rightarrow$ Roper $P_{11}(1440)$ Helicity amplitudes



- Sign change of $A_{1/2}$
- Gluonic excitation ruled out due to Q^2 dependence of both amplitudes.
- High Q^2 behavior consistent with radial excitation of the nucleon as in CQM

$S_{11}(1520)$ Helicity amplitudes



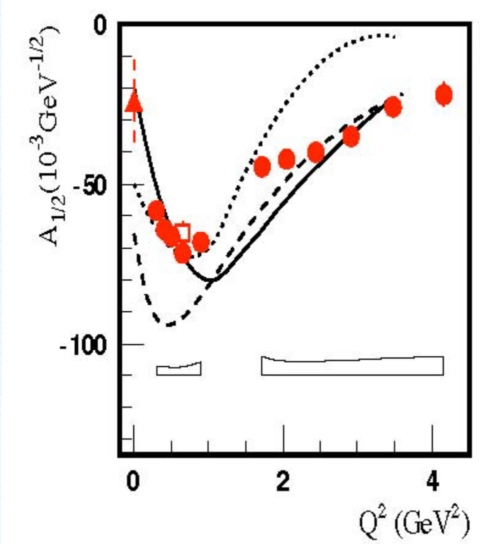
- Hard $A_{1/2}$ form factor confirmed (Slow fall-off as Q^2)
- First measurement of $S_{1/2}$. Sign inconsistent with CQM.

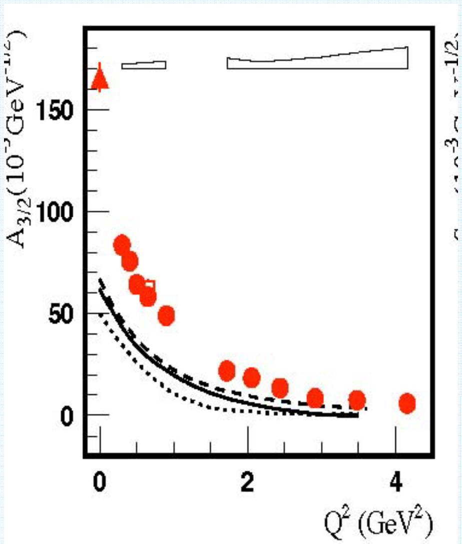
Helicity Amplitudes for $\gamma^* p \to D_{13}(1520)$

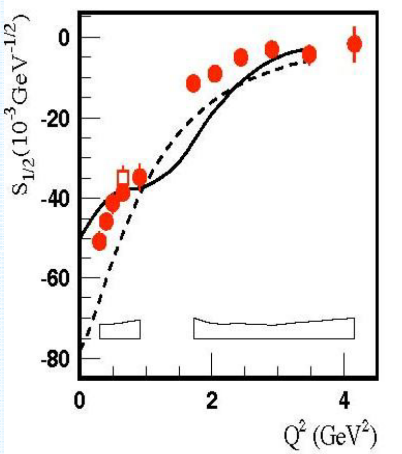
$$A_{hel} = \frac{A^2_{1/2} - A^2_{3/2}}{A^2_{1/2} + A^2_{3/2}}$$

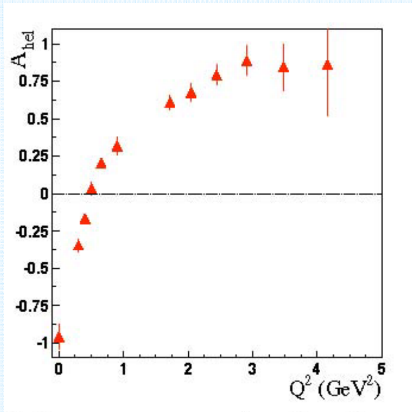
CQM predictions: $A_{1/2}$ dominance with increasing Q^2.

Also from helicity conservation.



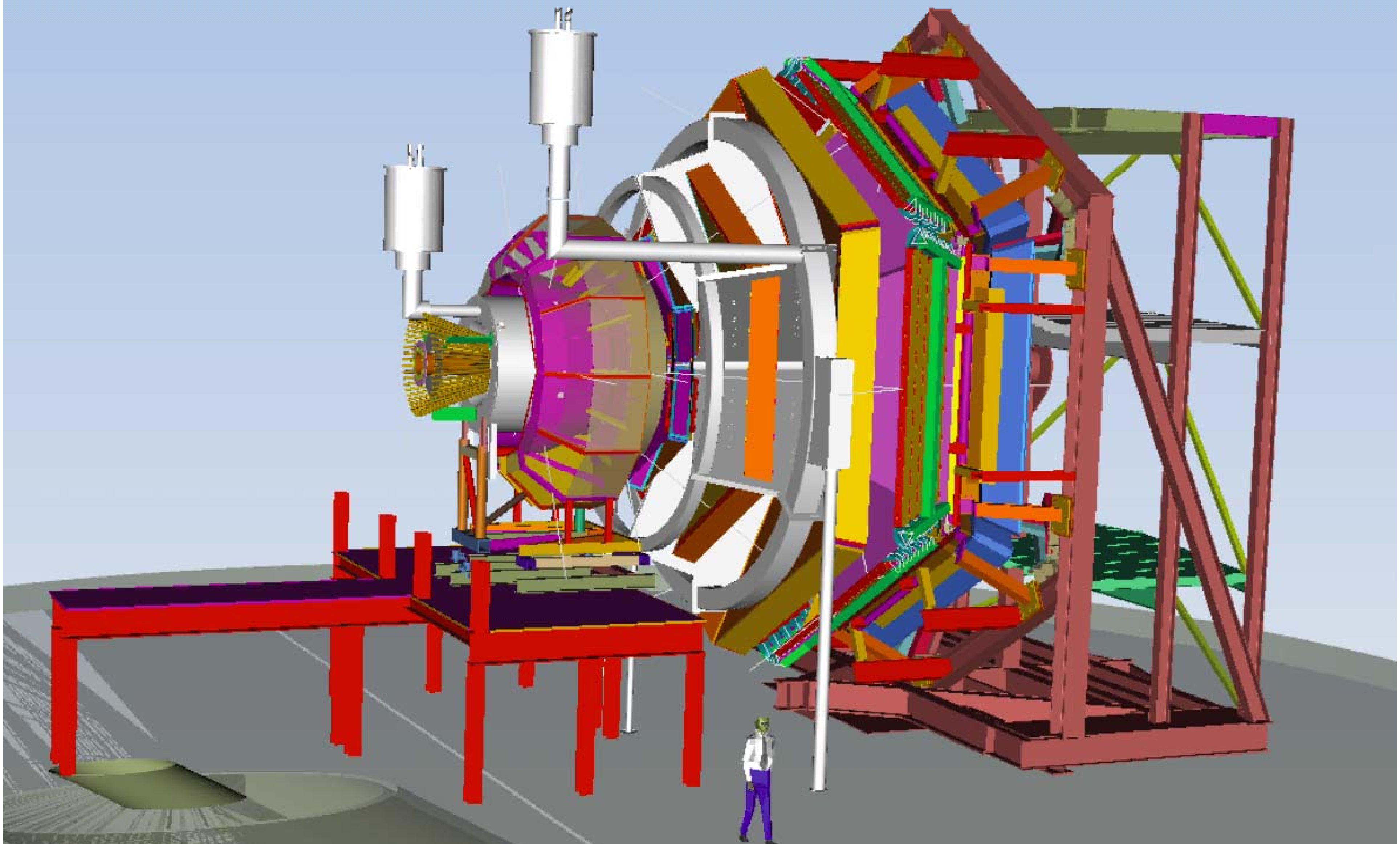






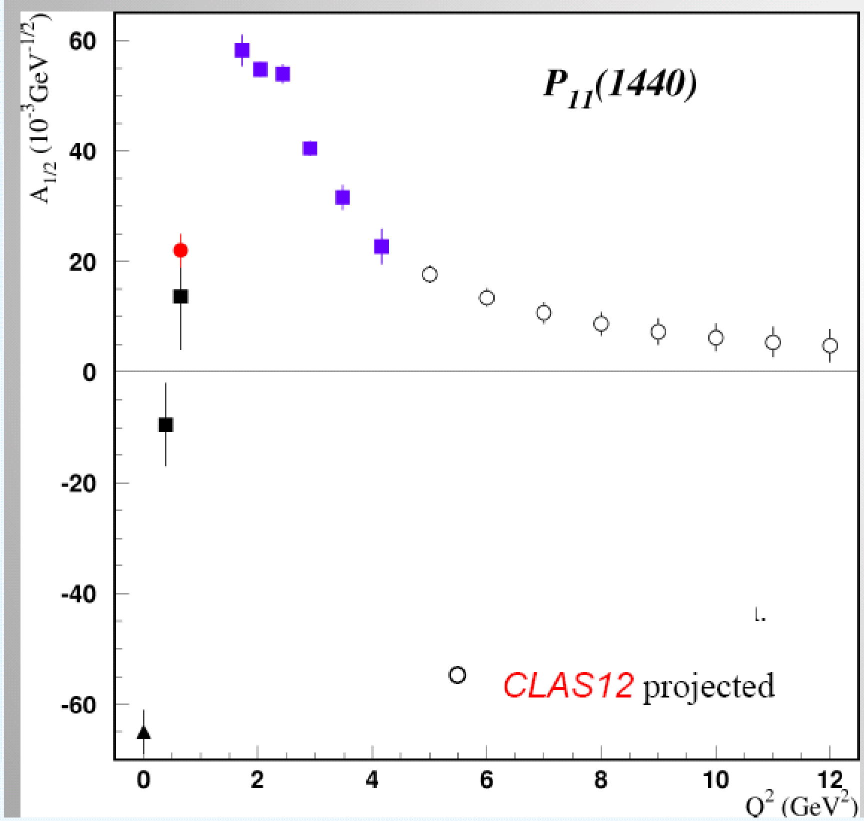
- Rapid switch of helicity structure from $A_{3/2}$ dominance to $A_{1/2}$ dominance at $Q^2 > 0.6\ GeV^2$

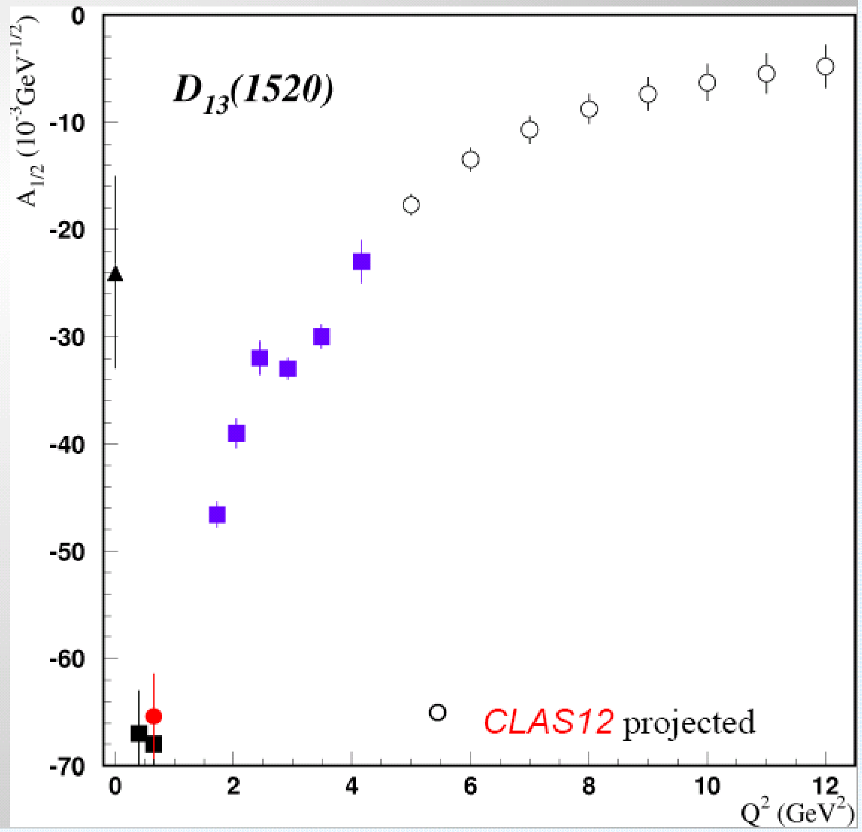
CLAS12 - Detector



Projections for N* Transition Amplitudes @ 12 GeV

Probe the transition from effective degrees of freedom, e.g. constituent quarks, to elementary quarks, with characteristic Q^2 dependence.





Summary

- New accurate measurements on Q^2 dependence of transition form factors of low lying excited states of the nucleon.

- More analysis results on transition form factors of higher mass states.

- Extensive program is underway with polarized photon beams and polarized targets to search for new baryon states.

- Approved proposal for a transition form factor program at high Q_2 at the Jlab 12 GeV upgrade with CLAS12.