Nucleon Resonances

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Introduction

Missing resonances

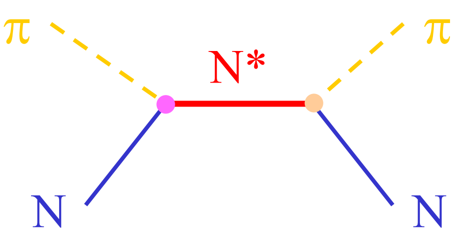
$N \rightarrow \Delta$ transition

Summary

Physics Goals

- Understand QCD in the strong coupling regime
  - example: bound qqq systems
  - mass spectrum, quantum numbers of nucleon excited states
  - what are the relevant degrees-of-freedom
  - wave function and interaction of the constituents

- Source of information
  - dominated by pion-induced reactions (mostly $\pi N \rightarrow \pi N$)
  - advantage:
    - strong coupling → large cross sections
    - simple spin structure
    - good quality beams
  - disadvantage: no structure information
    insensitive to states with weak πN coupling



Theoretical Models

- Constituent quark model
  - 3 constituent quarks
  - all 3 contribute to number of states
  - non-relativistic treatment (typically)

- Refinements of the constituent quark model
  - restore relativity
  - hadronic form factors
  - coupling between decay channels

- Lattice gauge calculations

Program Requirements

Experiment

large high-quality data set for N^* excitation covering

- a broad kinematical range in Q^2, W, decay angles
- multiple decay modes (π, $\pi\pi$, η, ρ, ω, K)
- polarization information (sensitive to interference terms)

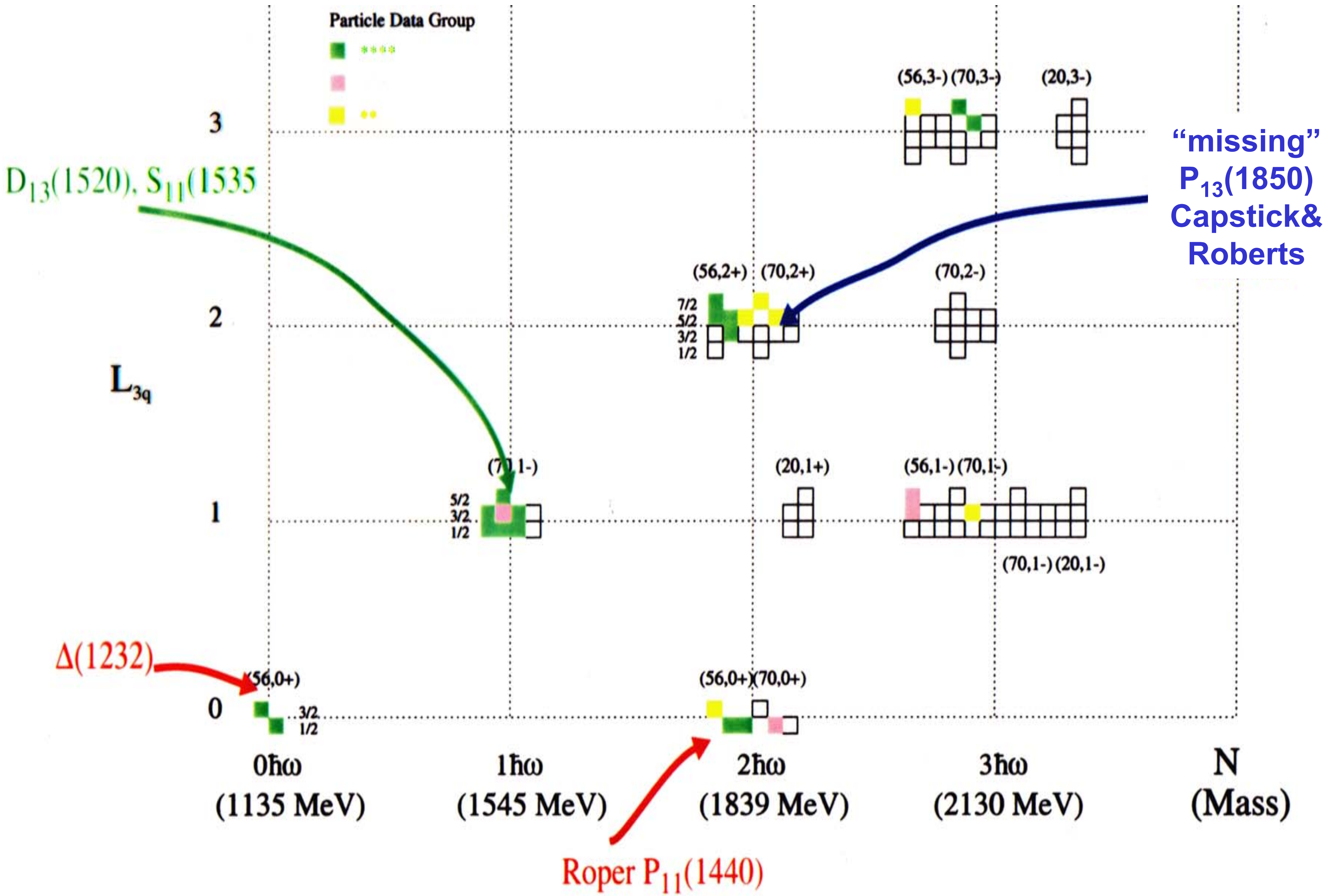
Analysis

$\Delta(1232)$: full Partial Wave Analysis possible
(isolated resonance, Watson theorem)

higher resonances

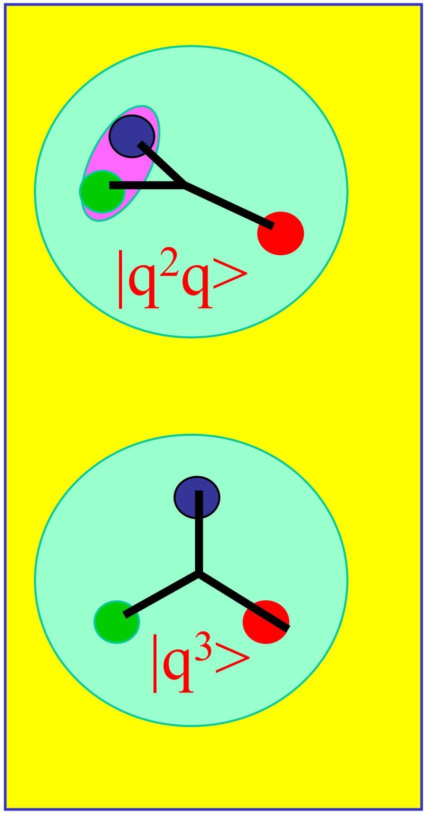
- need to incorporate Born terms, unitarity, channel coupling
- full PWA presently not possible due to lack of data (polarization)
  (substitute by assuming energy dependence of resonance)
- skills required at the boundary between experiment and theory

Quark Model Classification of N*



“Missing” Resonances?

Problem: symmetric CQM predicts many more states than have been observed (in πN scattering)



Two possible solutions:

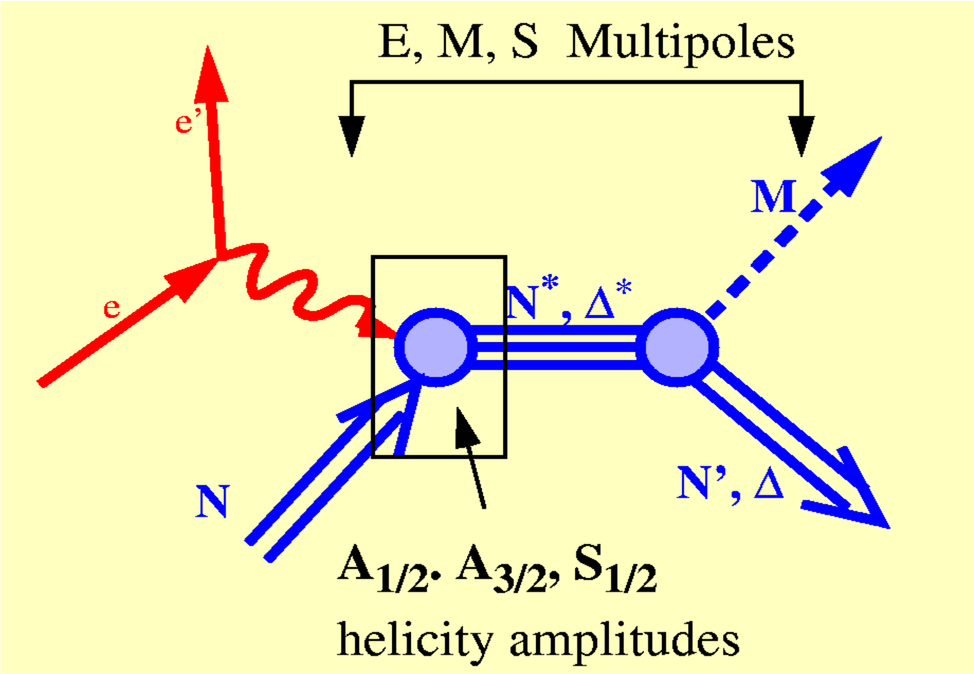
1. di-quark model
   fewer degrees-of-freedom
   open question: mechanism for q^2 formation?

2. not all states have been found
   possible reason: decouple from πN-channel
   model calculations: missing states couple to
   $N\pi\pi$ ($\Delta\pi$, $N\rho$), $N\omega$, KY

γ coupling not suppressed $\rightarrow$ electromagnetic excitation is ideal

Electromagnetic Probe

- helicity amplitudes very sensitive to the difference in wave functions of N and N*



- can separate electric and magnetic parts of the transition amplitude

- varying Q^2 allows to change the spatial resolution and enhances different multipoles

- **sensitive to missing resonance states**

Standard Analysis Approach

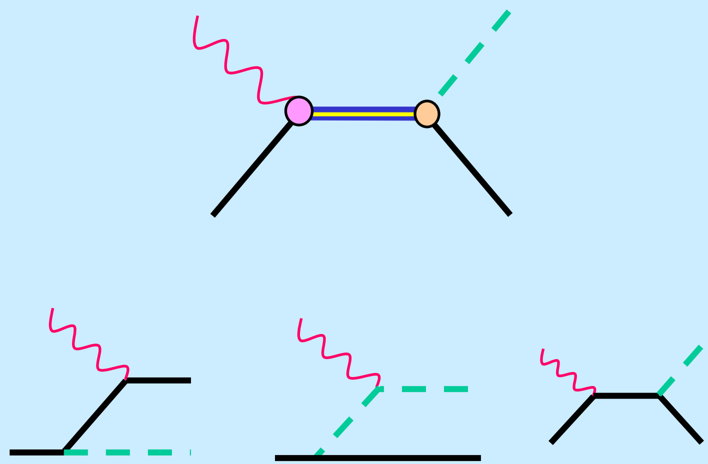
known resonance parameters

(mass, width, quantum numbers, hadronic couplings)

photo- and electro-production data base

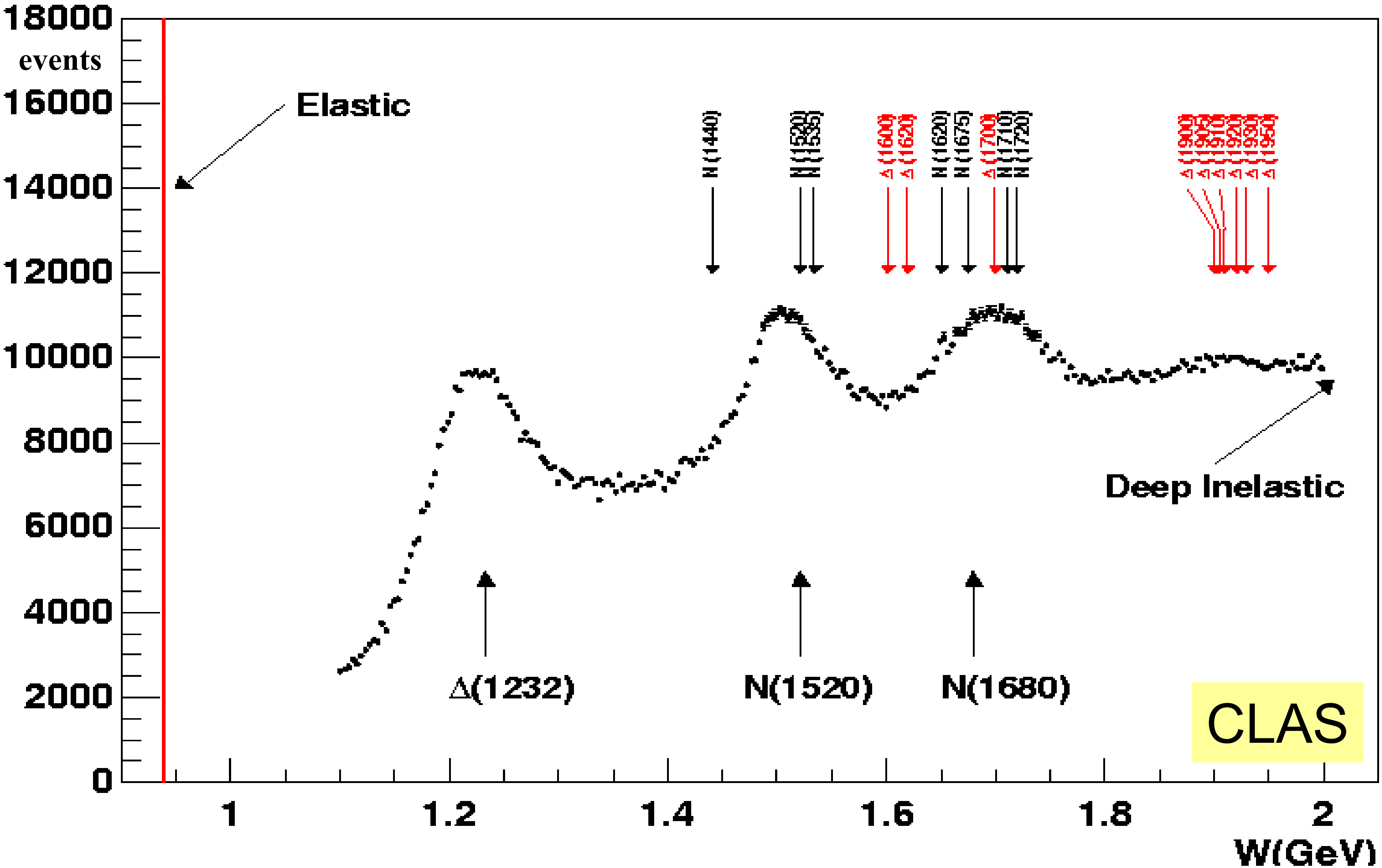
(mostly differential cross sections)

Analysis



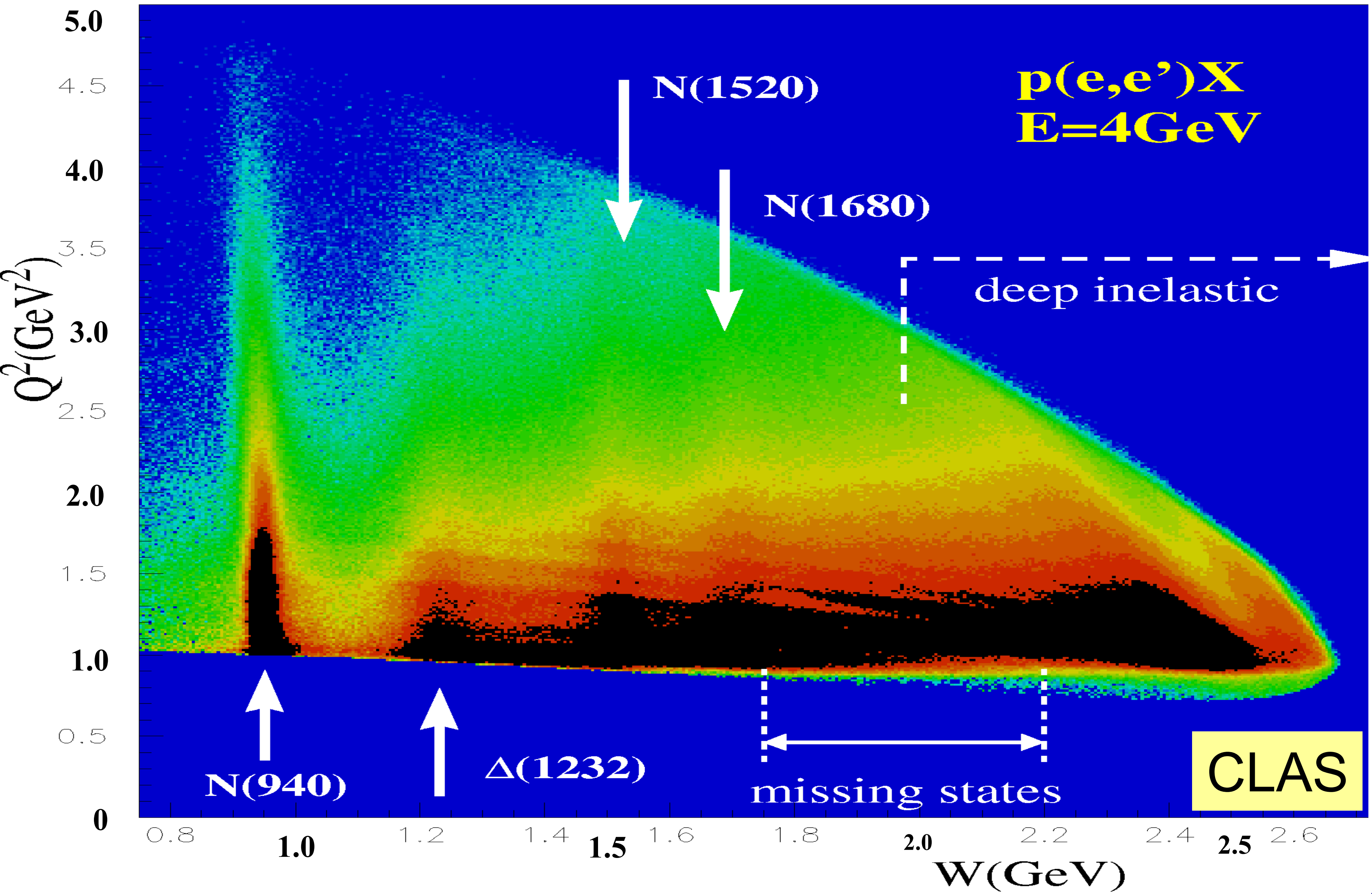
electromagnetic transition form factors

e p → e X at 4 GeV

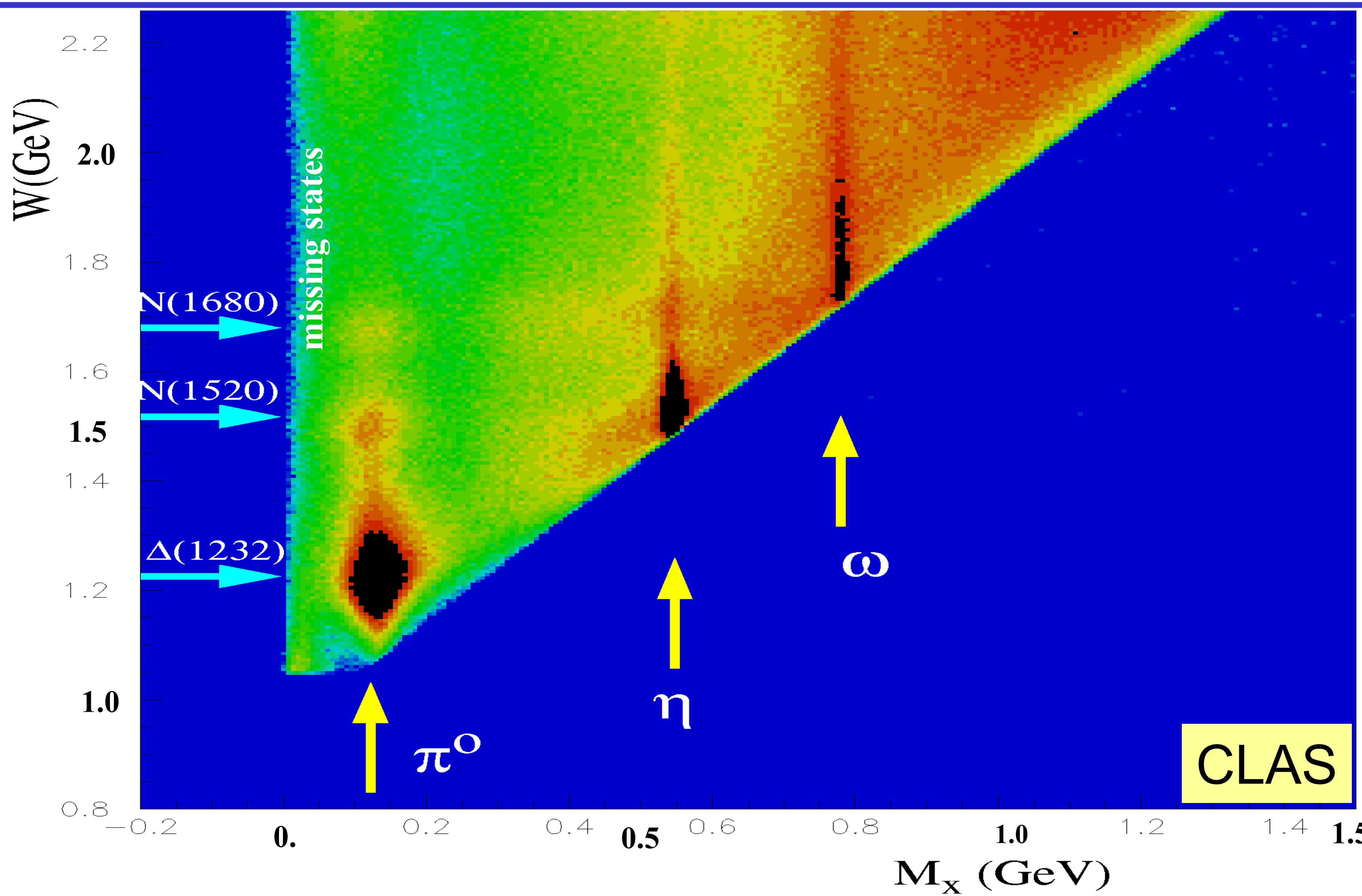


events
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
Elastic
N (1440)
N (1520)
N (1535)
Δ (1600)
Δ (1620)
N (1620)
N (1675)
Δ (1700)
N (1710)
N (1720)
Δ(1232)
N(1520)
N(1680)
Deep Inelastic
CLAS
1
1.2
1.4
1.6
1.8
2
W(GeV)

CLAS Coverage for $e\,p \rightarrow e'\,X$

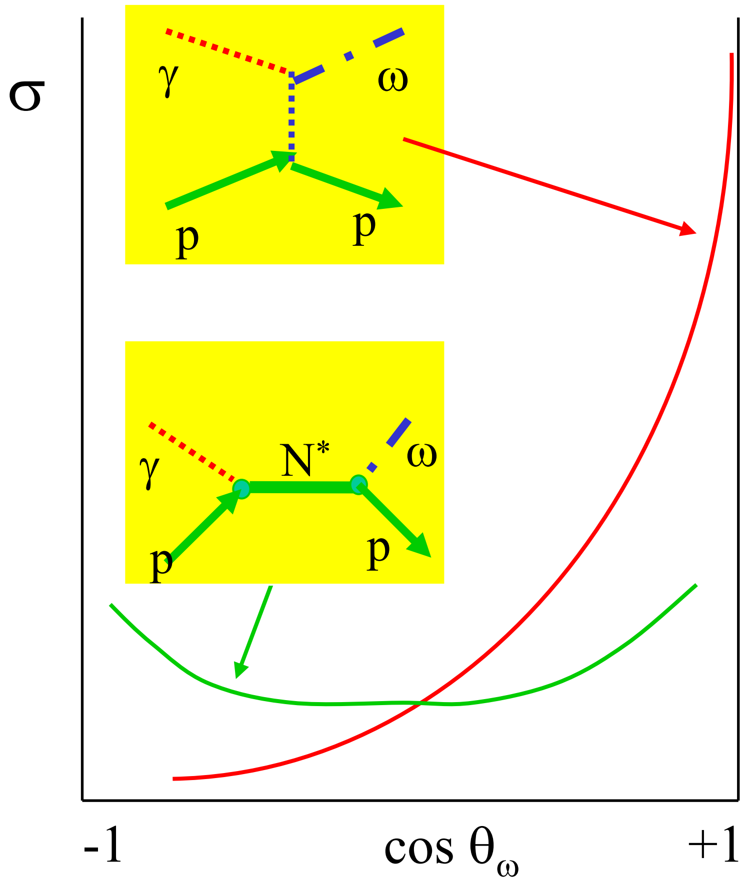


CLAS Coverage for $e\,p \rightarrow e'\,p\,X$, E=4 GeV



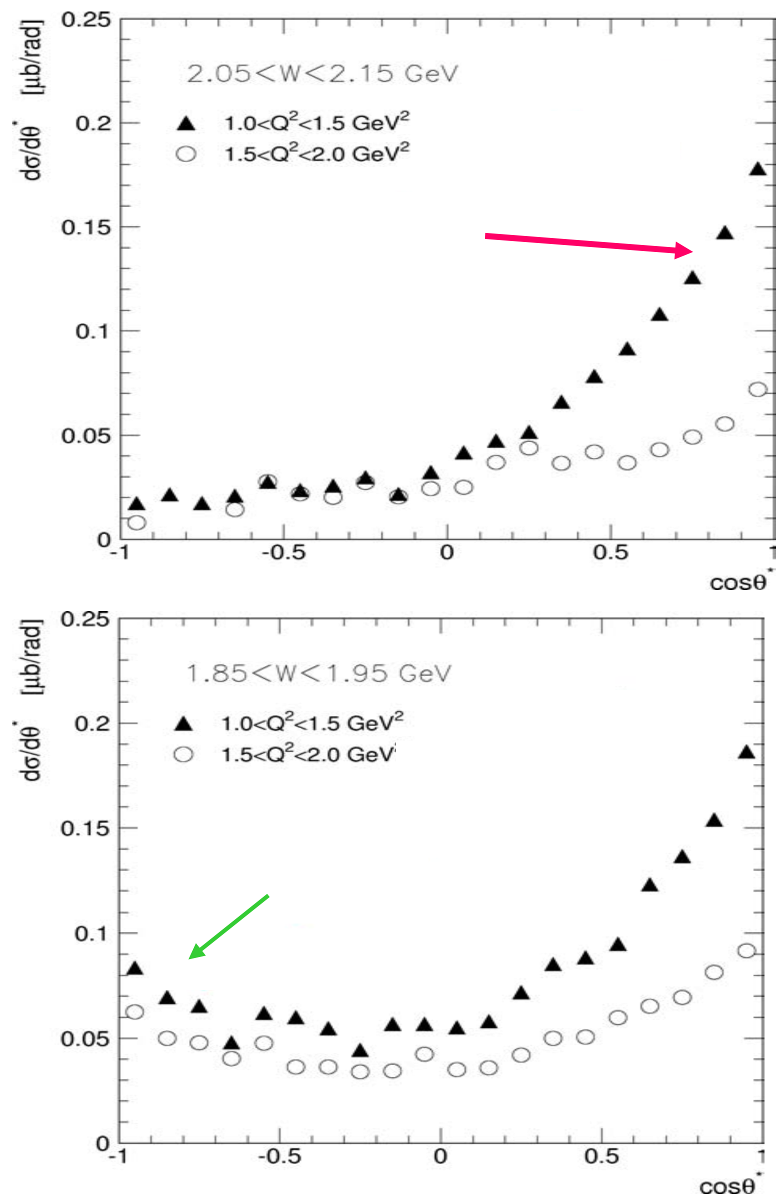
Resonance Contributions to $\gamma^* p \rightarrow p\omega$?

CLAS



above resonance region

in resonance region



Resonances in Hyperon Production?

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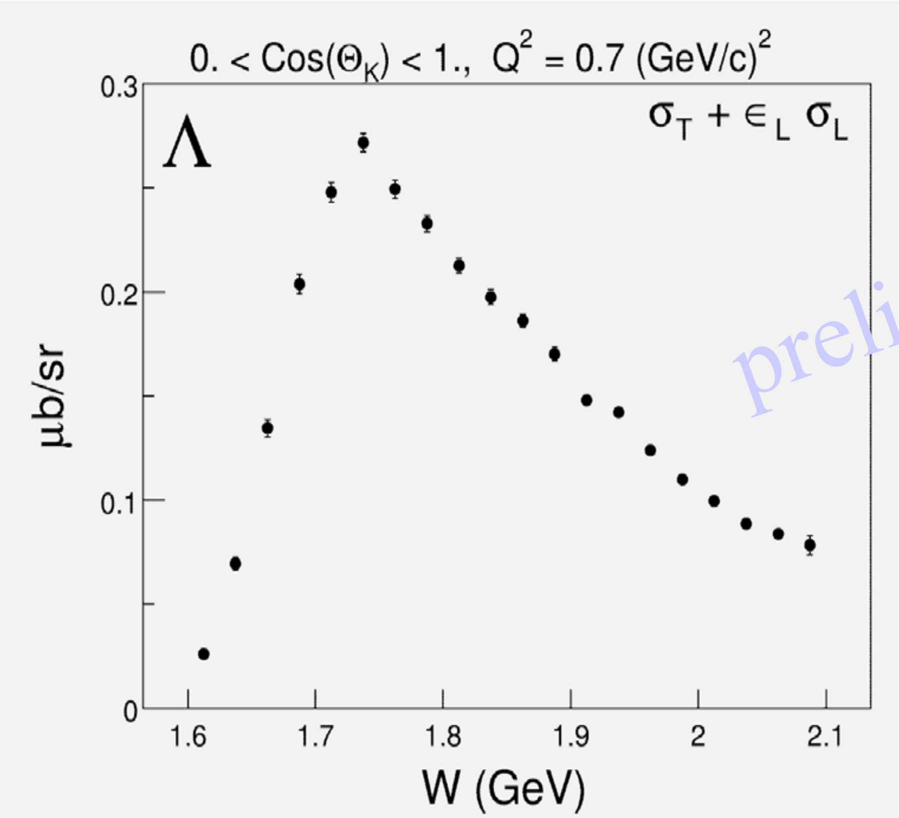
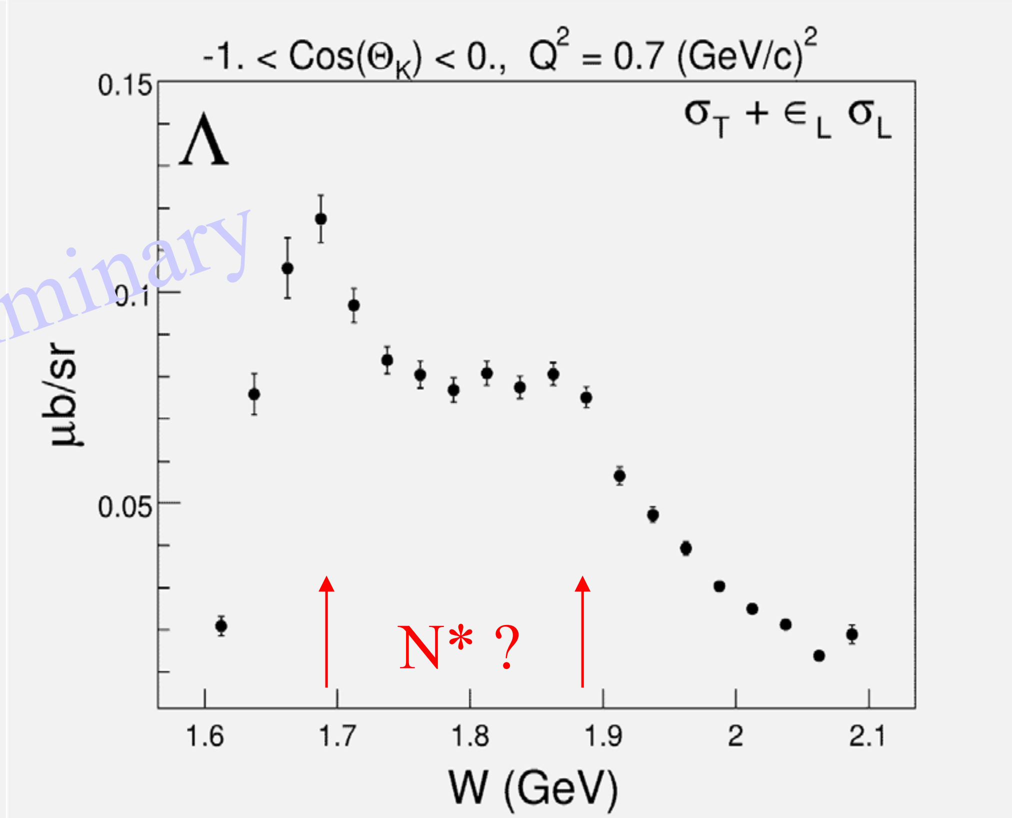
$$\gamma^* p \longrightarrow K^+ Y$$

forward hemisphere



backward hemisphere



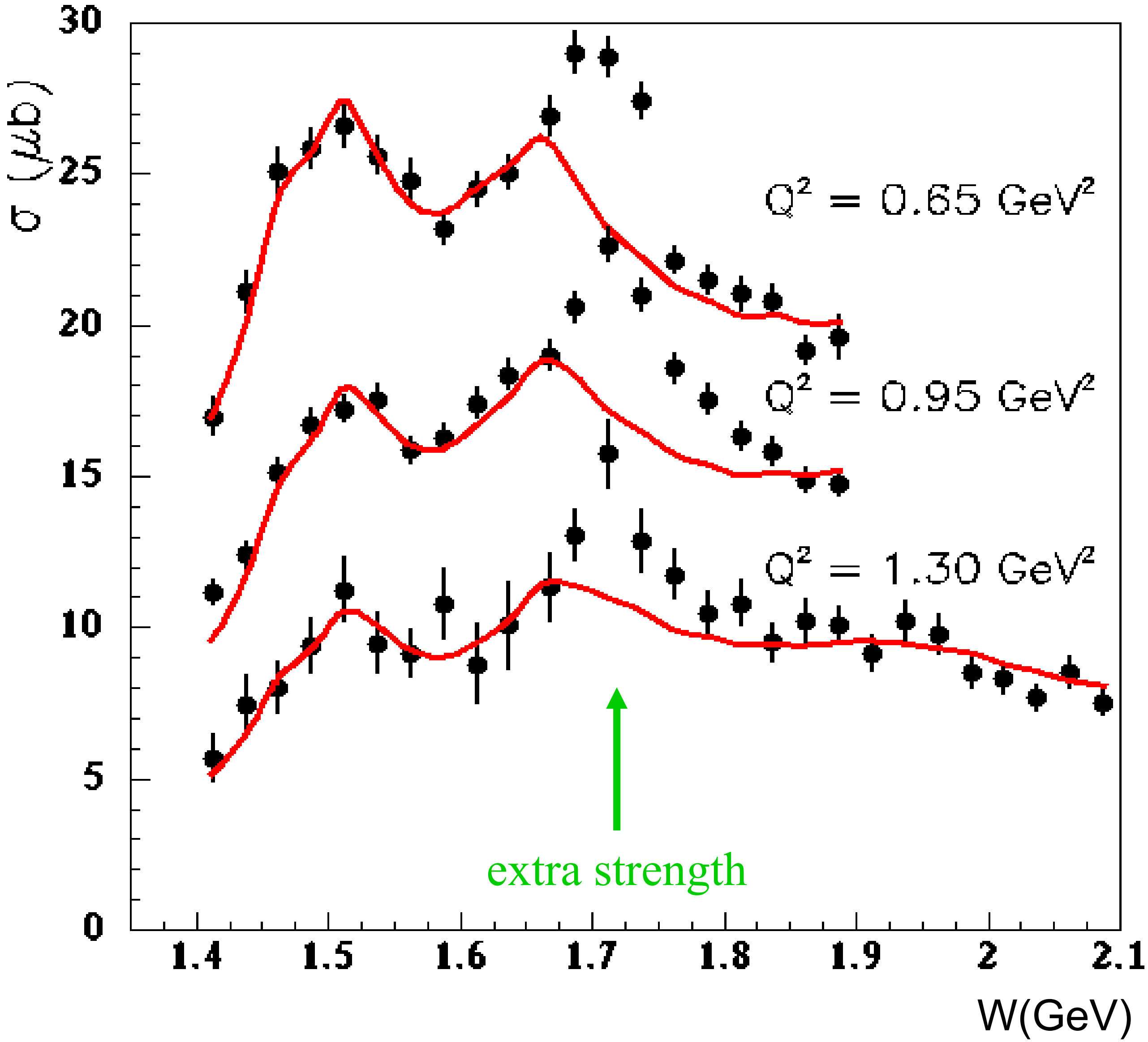
Resonances in $\gamma^* p \longrightarrow p\pi^+\pi^-$

Analysis performed by Genova-Moscow collaboration

step #1:

use the best information presently available

$\Gamma_{N\pi\pi}$ from PDG
$\Gamma_{N\gamma}$ AO/SQTM



Attempts to fit observed extra strength

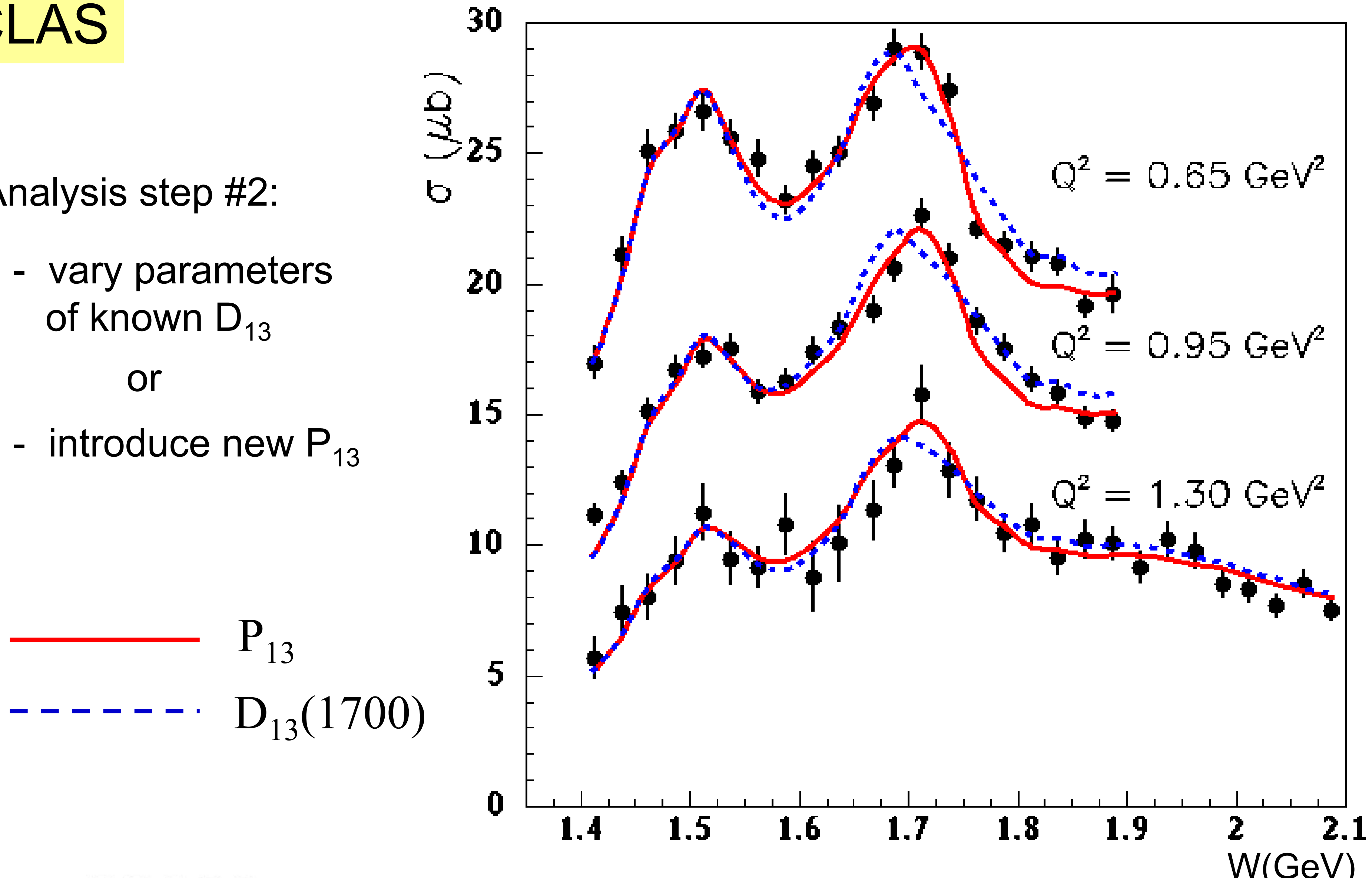
CLAS

Analysis step #2:

- vary parameters of known D_{13}

  or

- introduce new P_{13}



Summary of $\gamma^* p \rightarrow p \pi^+ \pi^-$ Analysis

CLAS data at variance with N* information in PDG

Describing data requires

- major modifications of the parameters of known resonances, or
- introduction of new P_{13} resonance with

  (consistent with "missing" P_{13} state, but mass lower than predicted)

$M = 1.72 +/- 0.02$ GeV

$\Gamma_T = 88 +/- 17$ MeV

$\Delta \pi : 0.41 +/- 0.13$

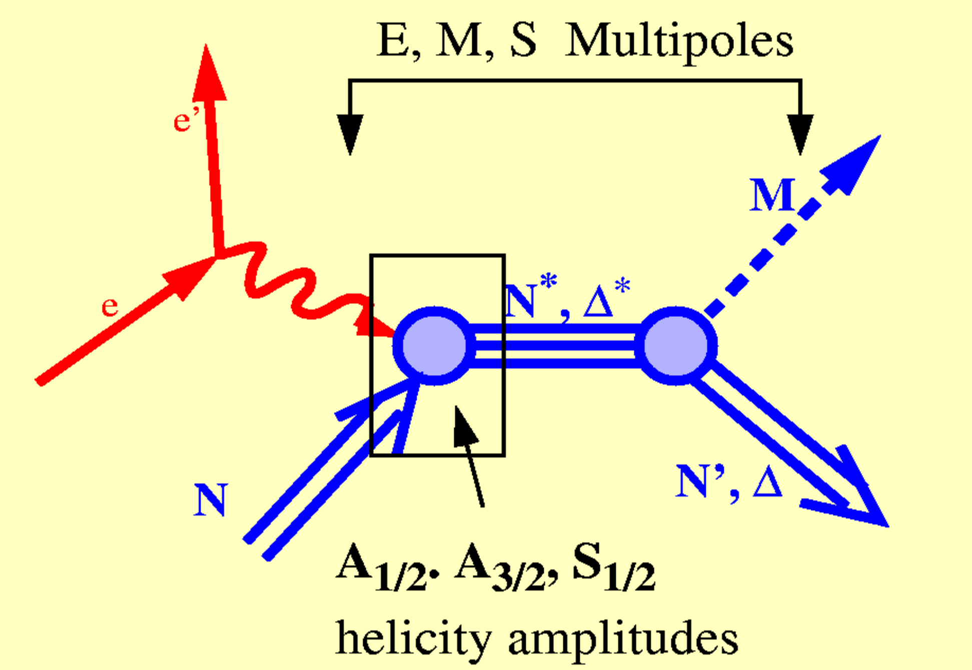
$N \rho : 0.17 +/- 0.10$

Next steps:

- more experimental data already in hand
- combined analysis with other decay channels: πN, ηN, $K \Lambda$

Electromagnetic Probe

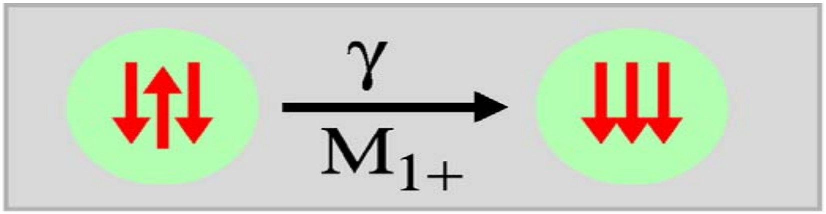
- helicity amplitudes very sensitive to the difference in wave functions of N and N*
- can separate electric and magnetic parts of the transition amplitude



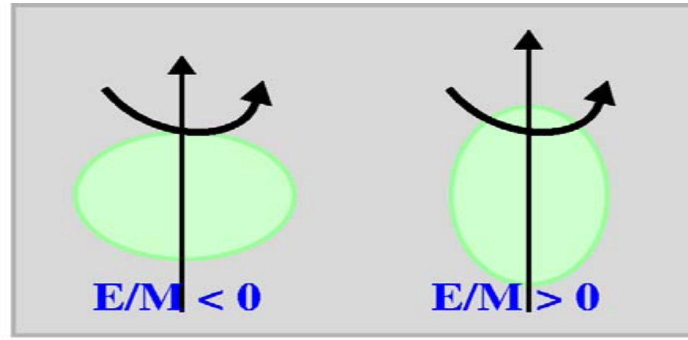
- varying Q^2 allows to change the spatial resolution and enhances different multipoles

- sensitive to missing resonance states

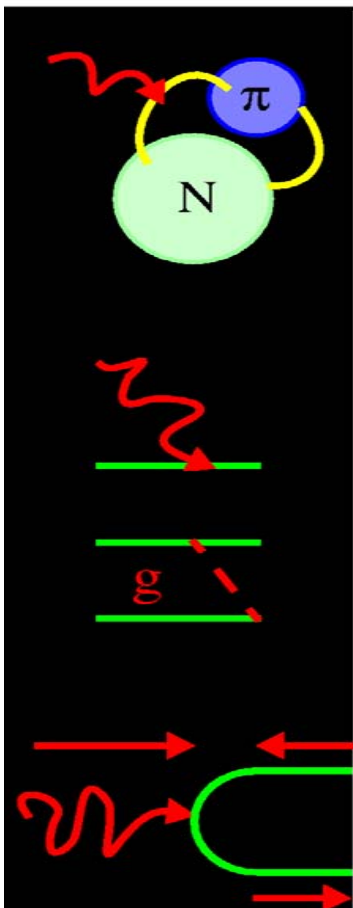
$N \rightarrow \Delta(1232)$ Transition Form Factors



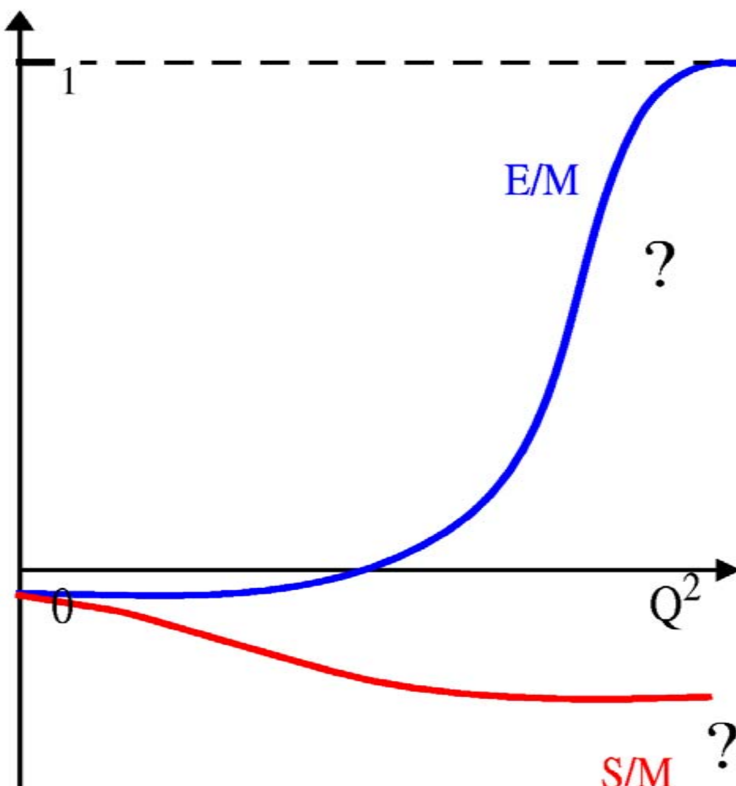
SU(6): $E_{1+} = S_{1+} = 0$



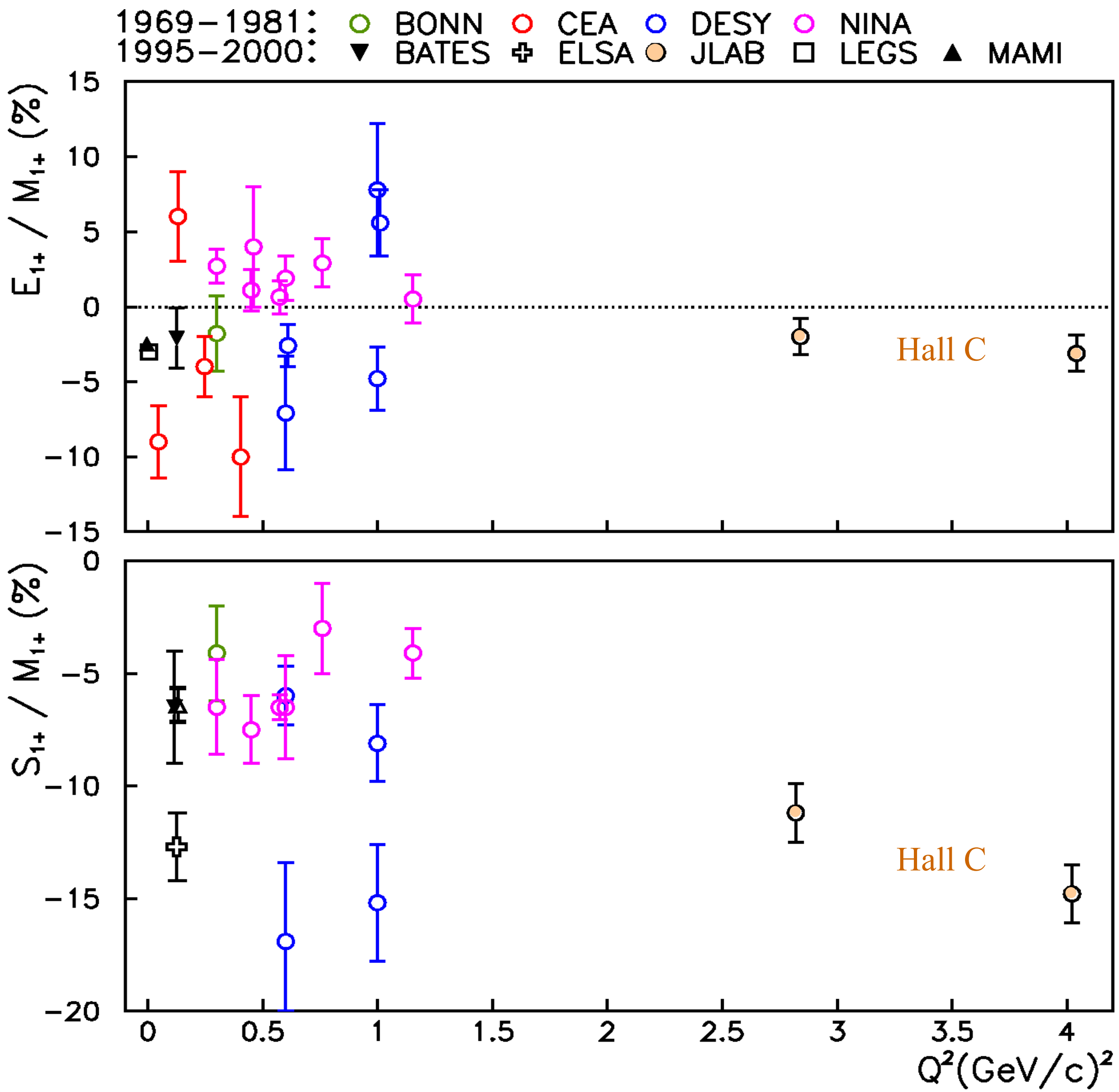
(A. Buchmann, E. Henley, 2000)



	E/M	S/M
pion cloud	~0.03	~0.1
one-gluon exch.	~ 0.01	
pQCD	+1	const.



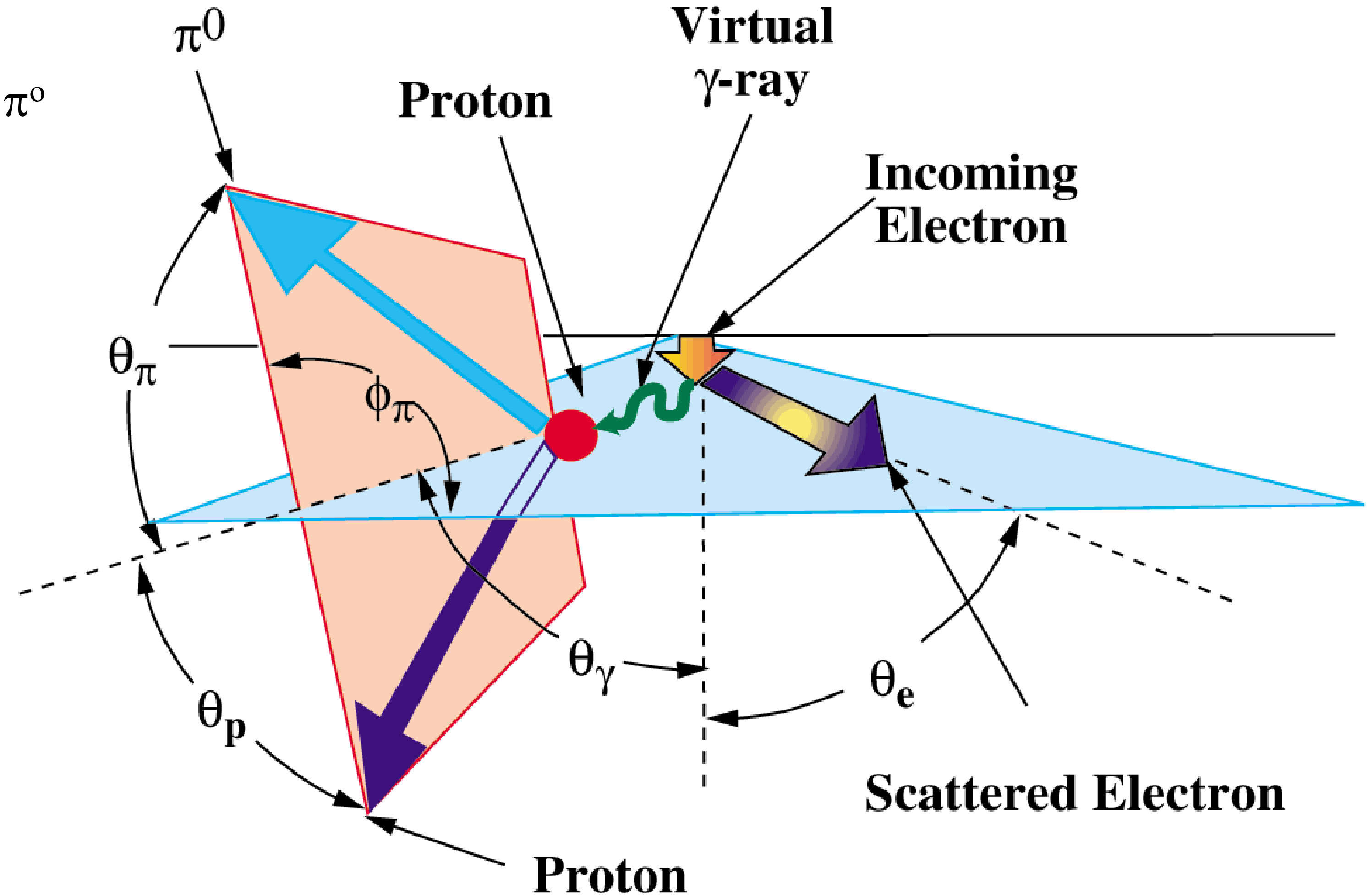
Multipoles E_{1+}/M_{1+}, S_{1+}/M_{1+} (before 2001)



Kinematics and Cross Sections

example:

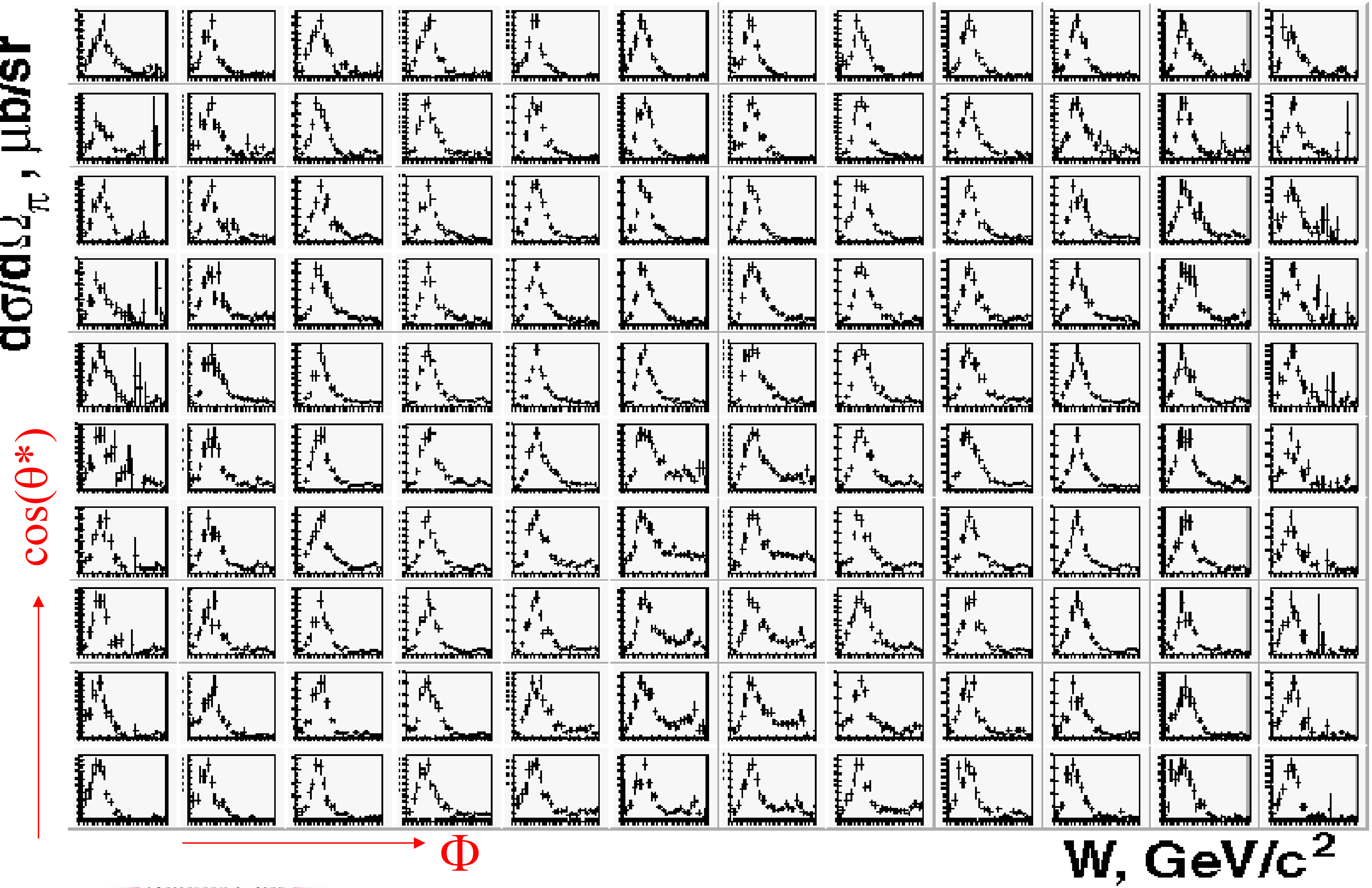
$e\, p \rightarrow e'\, p\, \pi^o$



$$\frac{d\,\sigma}{d\Omega_e dE'_e d\Omega_\pi} = \Gamma_t \left(\sigma_t + \varepsilon\sigma_l + \varepsilon\sigma_{tt} \cos 2\phi_\pi + \sqrt{2\varepsilon\,(\varepsilon+1)}\,.\,\sigma_{tl} \cos \phi_\pi \right)$$

CLAS

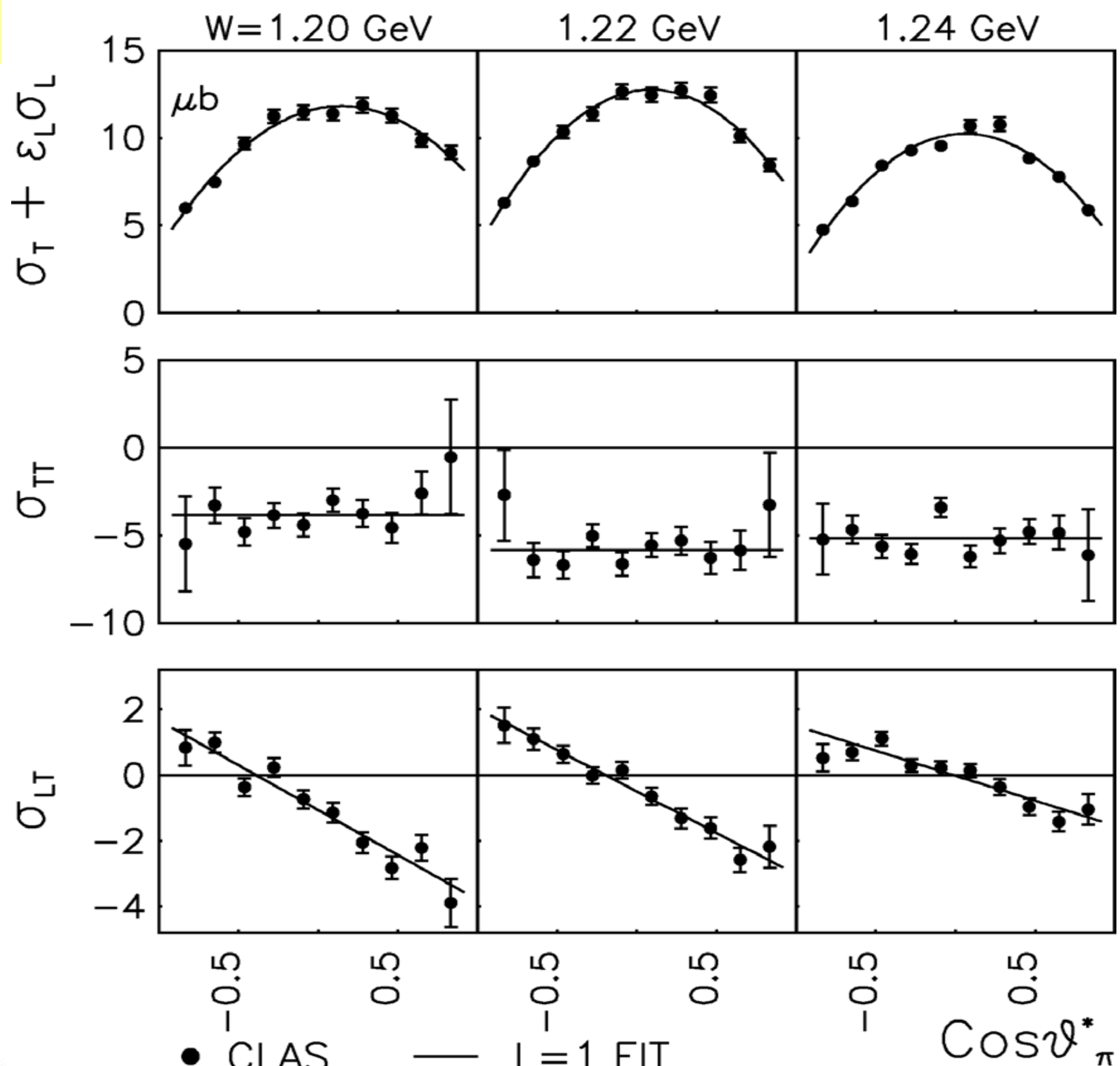
$Q^2=0.40(GeV/c)^2$, $\Delta Q^2=0.100(GeV/c)^2$



Multipole Analysis for $\gamma^* p \rightarrow p \pi^o$

CLAS

$Q^2 = 0.9\ GeV^2$

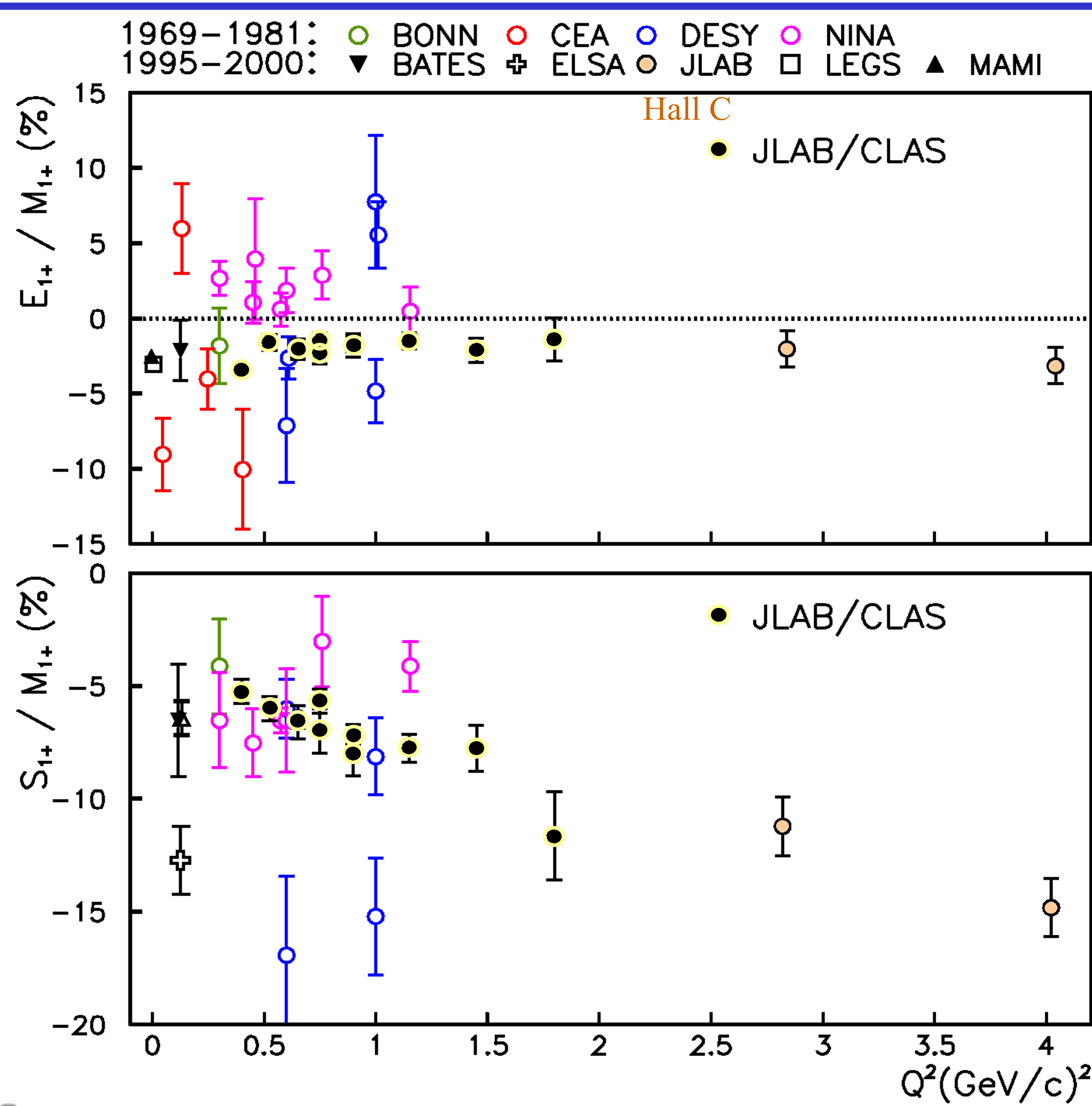


$|M_{1+}|^2$

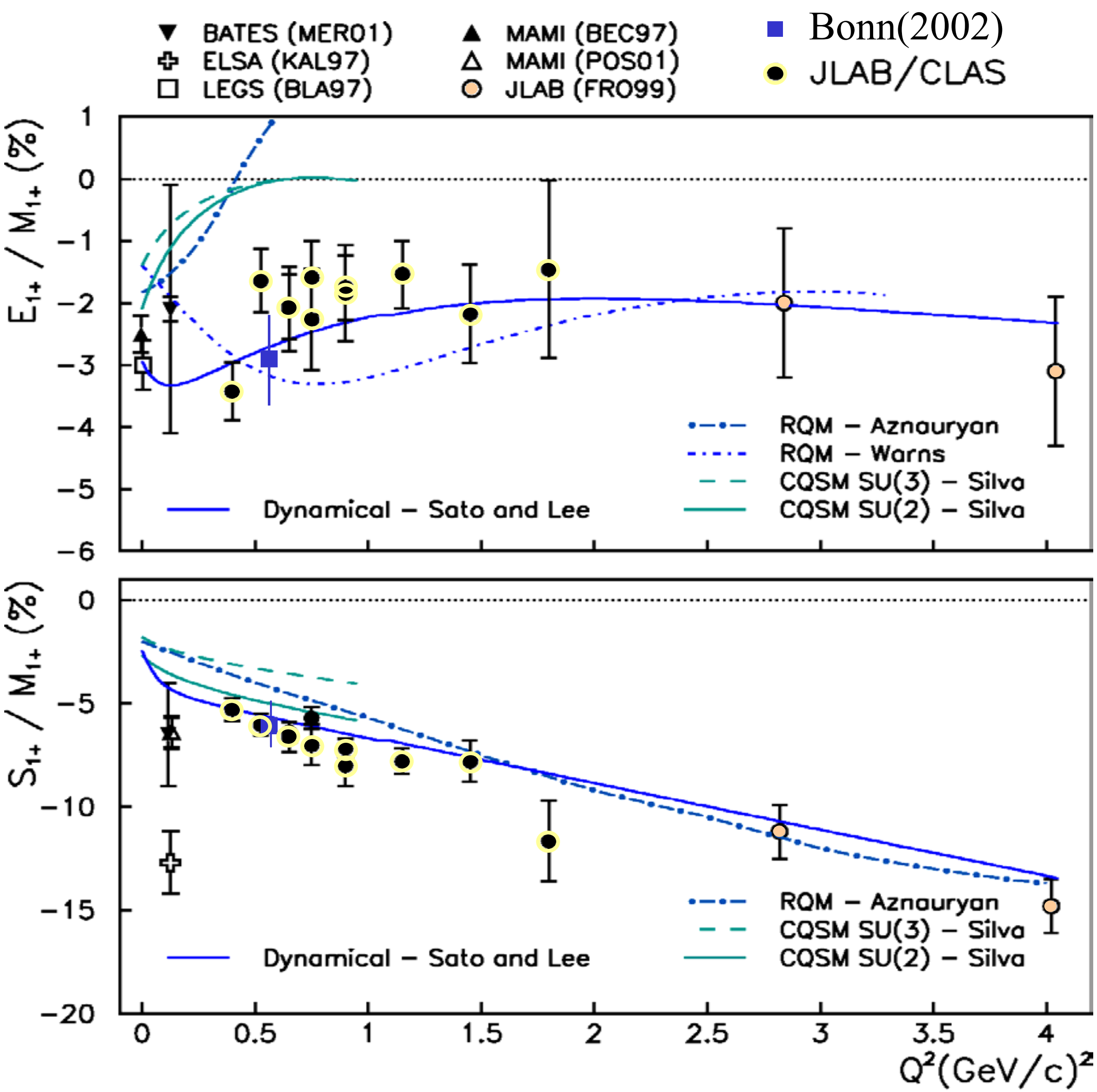
$Re(E_{1+}M_{1+}^*)$
$|M_{1+}|^2$

$Re(S_{1+}M_{1+}^*)$

Multipoles E_{1+}/M_{1+}, S_{1+}/M_{1+} (2002)



Theoretical Interpretation of E_{1+}/M_{1+}, S_{1+}/M_{1+}



$N \rightarrow \Delta$ Transition, what's next?

- systematic uncertainties in extraction of E_{1+}/M_{1+} from $ep \rightarrow e'p\,\pi^o$ around 0.5%
  - differences in treatment of background terms (models not constrained)
  - will become more severe for higher Q^2 (Δ dropping faster)

- more experimental information in hand (analysis in progress)
  - cross sections $e\,p \rightarrow e'p\,(\pi^o)$ $Q^2 = (1.5 - 5.5)\ GeV^2$ CLAS
  - single-spin asymmetry $\sigma_{TL'}$ for $\vec{e}\,p \rightarrow e'p\,(\pi^o)$ and $\vec{e}\,p \rightarrow e'\,\pi^+\,(n)$ CLAS
  - polarization transfer in $\vec{e}\,p \rightarrow e'\,\vec{p}\,(\pi^o)$ Hall A
  - differential cross sections for $e\,p \rightarrow e'\,\pi^+\,n$ (Δ less important) CLAS

- experiments in the near future
  - extend Q^2 range to 0.05 GeV^2 (end of 2002) CLAS
  - extend Q^2 range to ~7 GeV^2 (1st half of 2003) Hall C

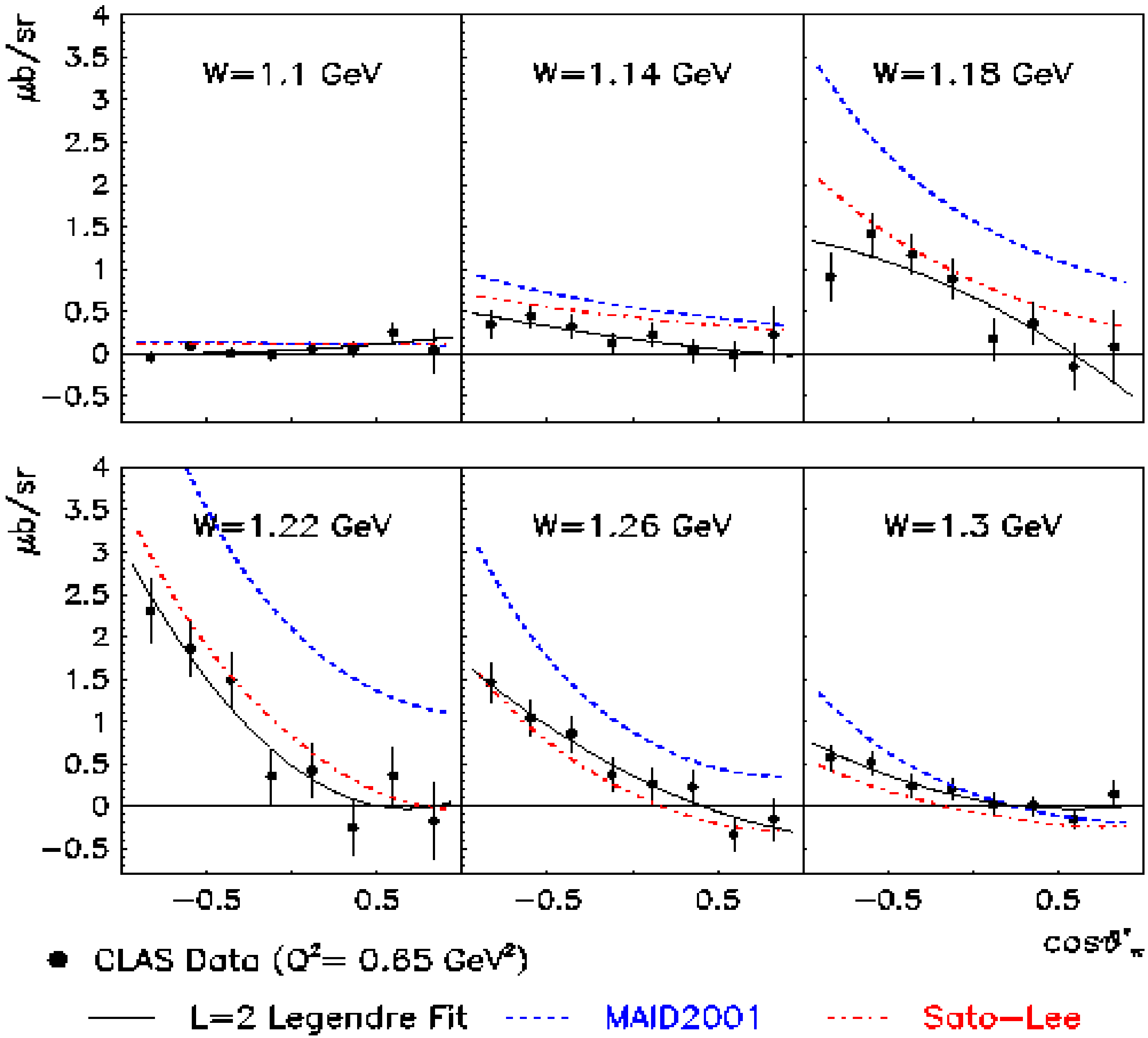
Polarized Beam Observables

CLAS

$\sigma_{LT'}$ response function for

$\vec{e}\, p \rightarrow e\, p\, \pi^o$

$\sigma_{LT'} = 0$ if only a single diagram contributes (sensitive to the interference between Δ and background)



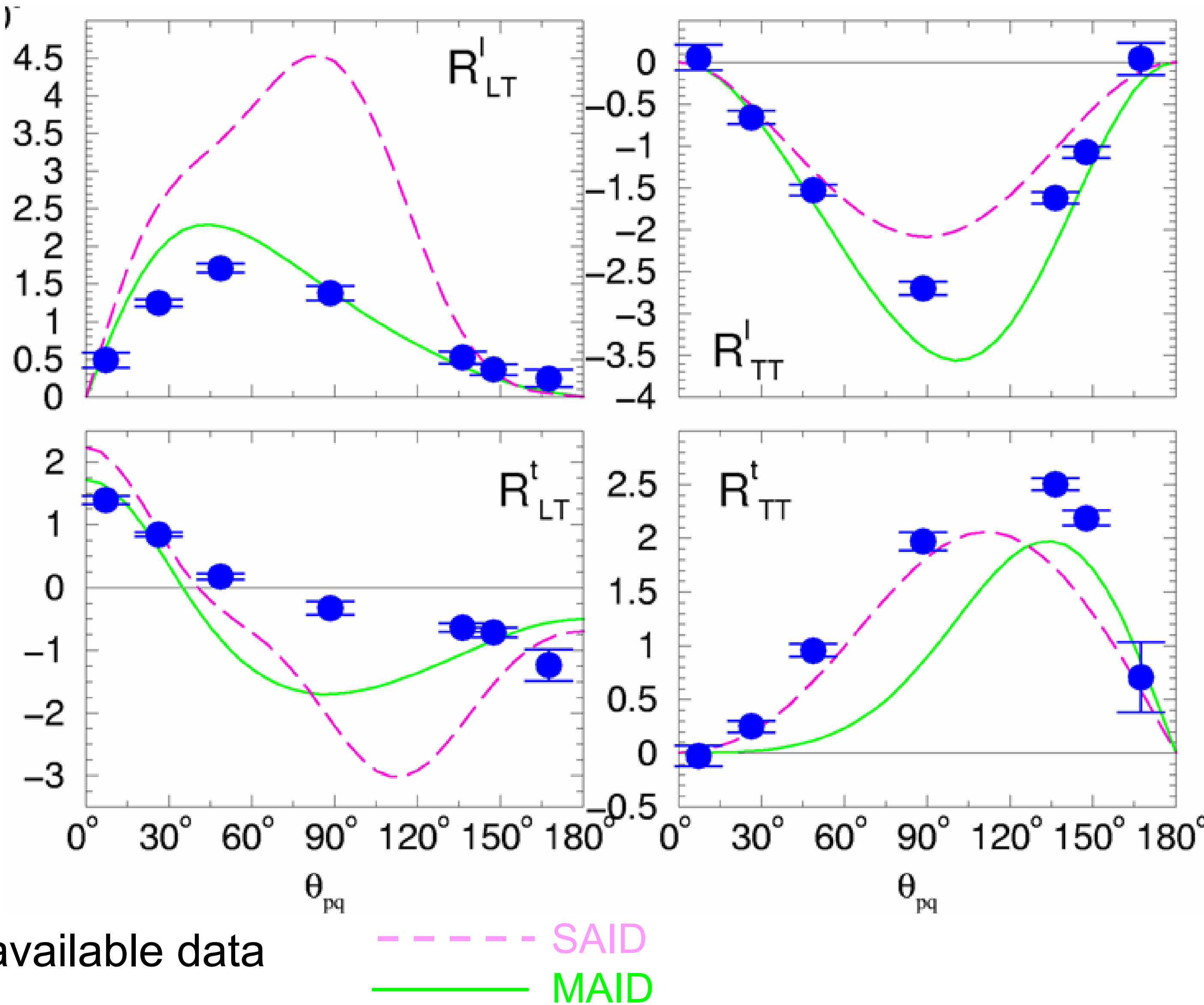
Polarization Measurement in $\vec{e}\, p \to e'\, \vec{p}\, (\pi^o)$

Hall A

$Q^2 = 1\ GeV^2$

$W = 1.232\ GeV$

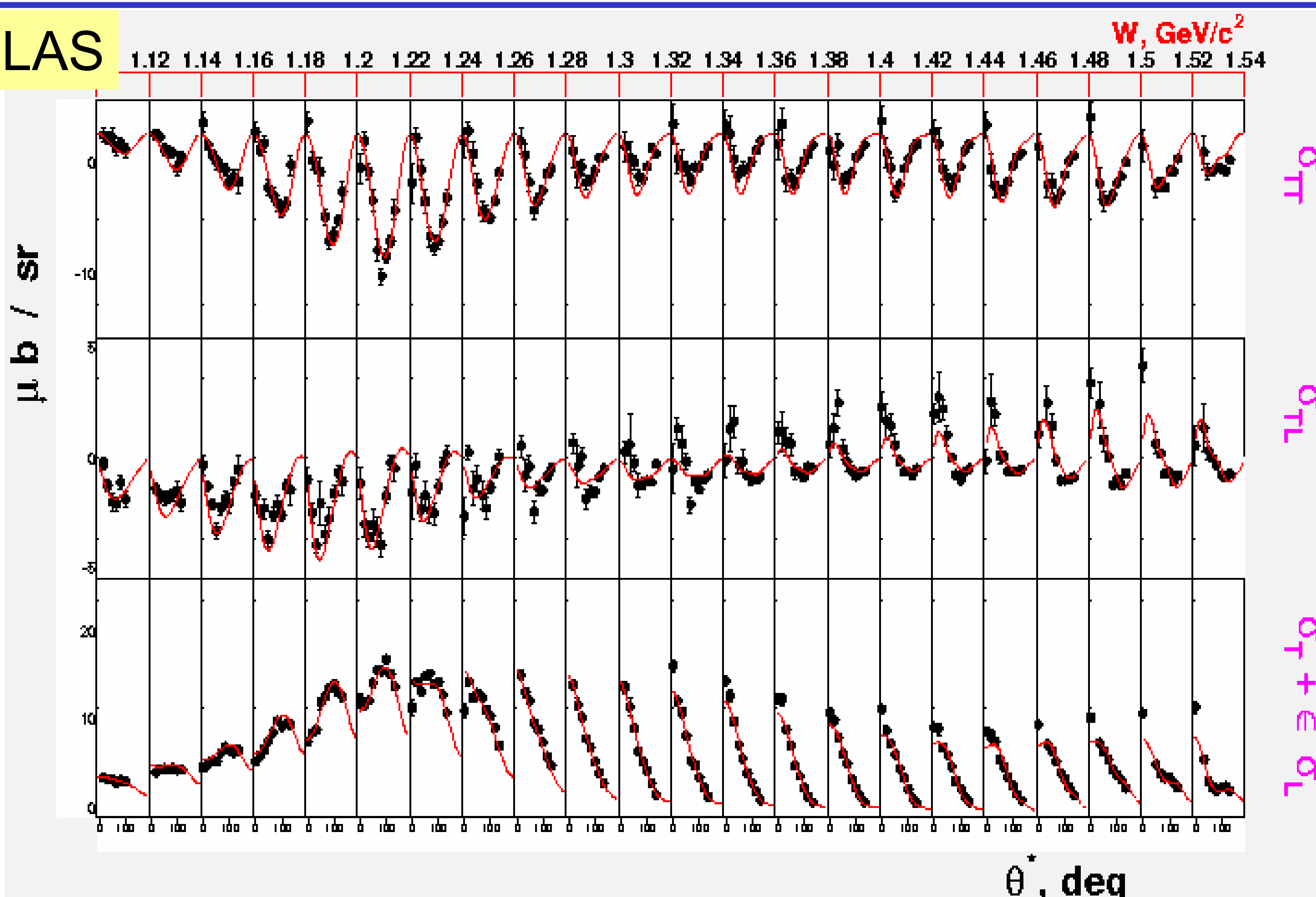
Results sensitive to non-resonant contributions



Parametrisations of available data

π^+ Electroproduction

CLAS



Summary

- Understanding the structure of bound qqq systems is a central problem for the study of QCD in the strong coupling regime

- Specific issue #1: identify relevant degrees-of-freedom
  - finally getting electromagnetic data of sufficient quality to study missing resonance problem
  - initial data strongly suggest resonance contributions that cannot be explained by known baryon states

- Specific issue #2: probing details of quark wave functions
  - consistent data set for $N \rightarrow \Delta$ transition up to $Q^2 = 4$ GeV^2
  - E_{1+}/M_{1+} small and negative
  - data emphasize the importance of pion degrees-of-freedom and relativity