Electroexcitation of Nucleon Resonances

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BARYONS '02

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Why Excitations of the Nucleon?

(Nathan Isgur, N*2000 Conference, Jlab)

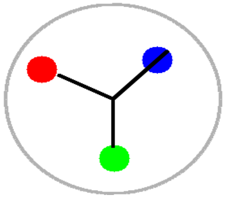
- Nucleons represent the real world, they must be at the center of any discussion on

“why the world is the way it is”

- Nucleons represent the simplest system where

“the non-abelian character of QCD is manifest”

symbol of BARYONS 2001



3-gluon vertex

- Nucleons/baryons are complex enough to

“reveal physics hidden from us in mesons”

Gell-Mann & Zweig - Quark Model

O. Greenberg - The Δ^{++} problem/color

OUTLINE

- Why electroproduction?

- Experimental results
  - ☐ Quadrupole deformation in the N-Δ transition
  - ☐ The Roper resonance - N'(1440)$1/2^+$
  - ☐ Eta production and the $N^*(1535)1/2^-$
  - ☐ SQTM and higher mass states
  - ☐ Resonances in multi-pion, and KY^* channels?

- Summary/Outlook

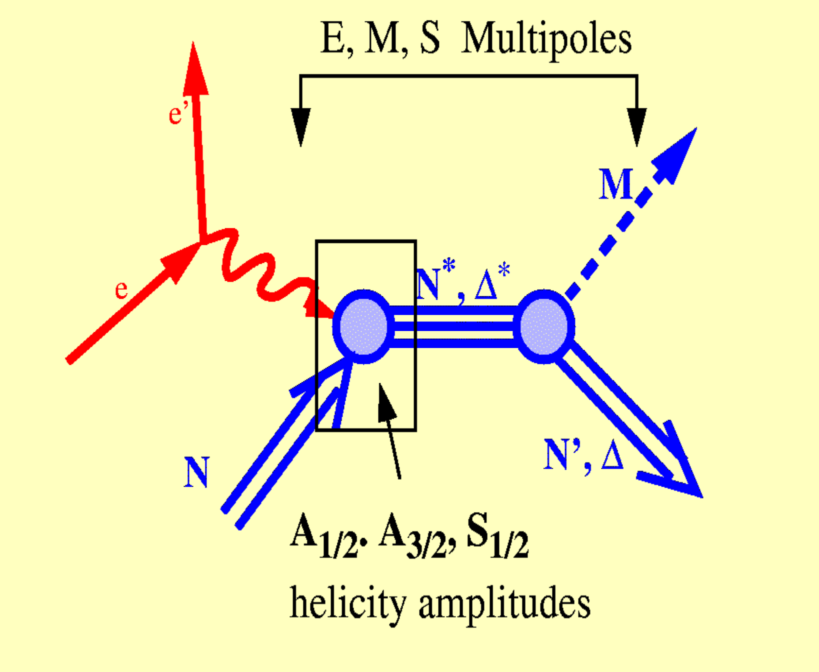
Why N* Electroproduction?

- ☐ Light quark baryon spectrum for $N^* \not\rightarrow N\pi$

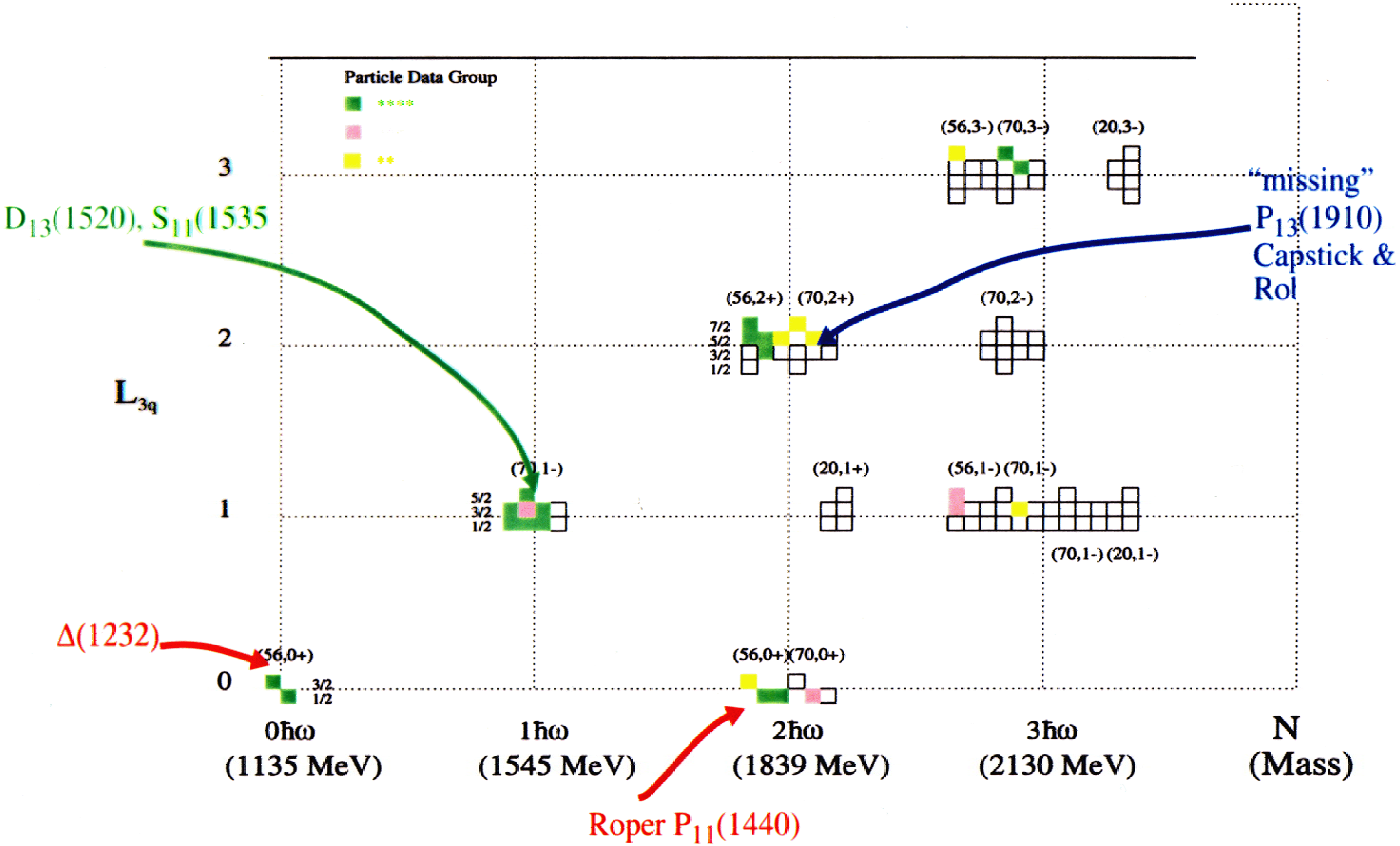
- ☐ Internal structure of baryons

  → Helicity amplitudes vs Q^2 => Relevant *degrees of freedom* vs distance scale

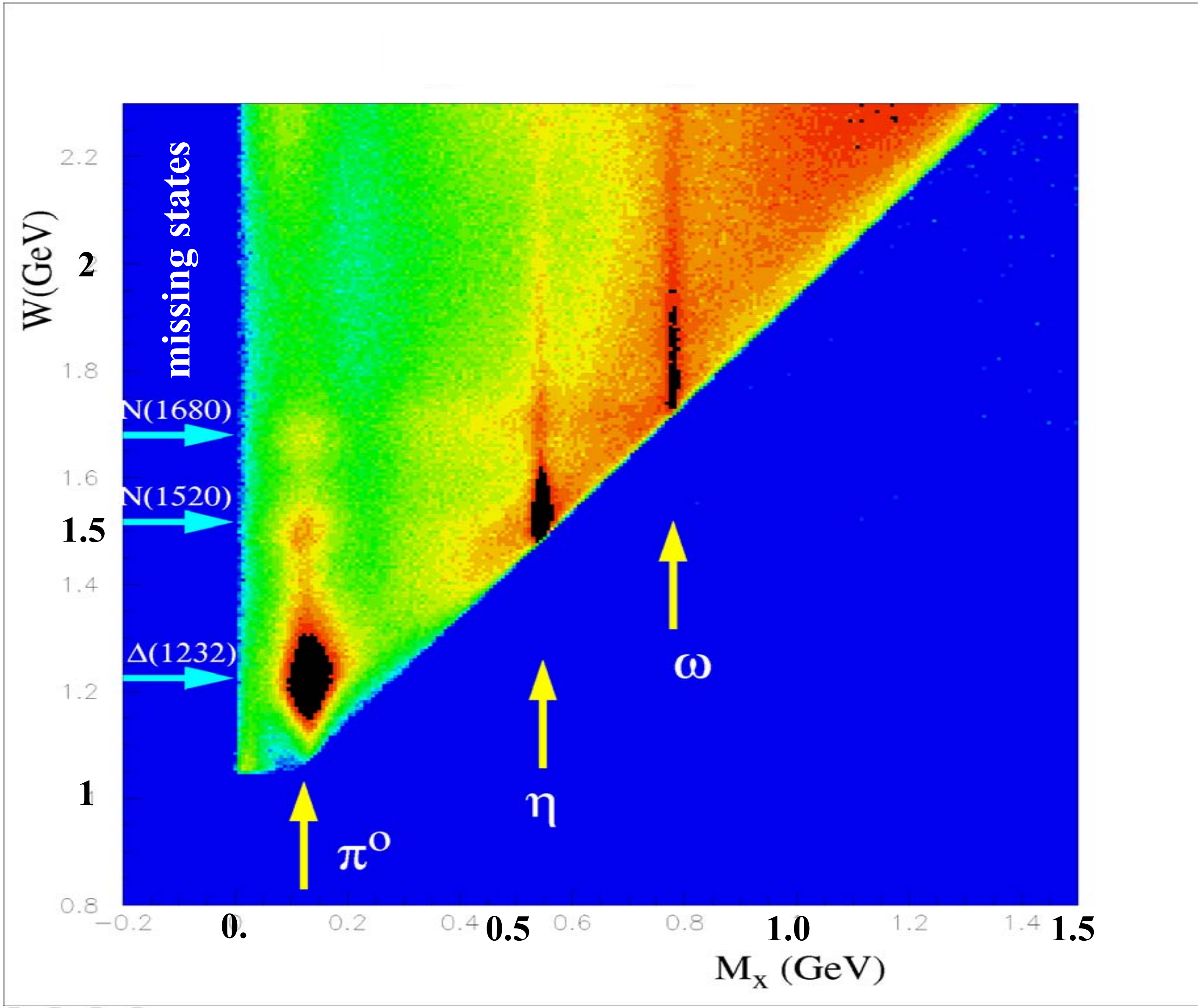
- ☐ Meson production mechanism



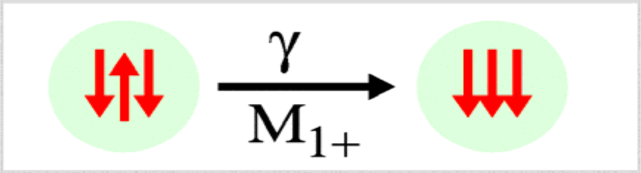
Lowest Supermultiplets in SU(6)O(3) Symmetry Group



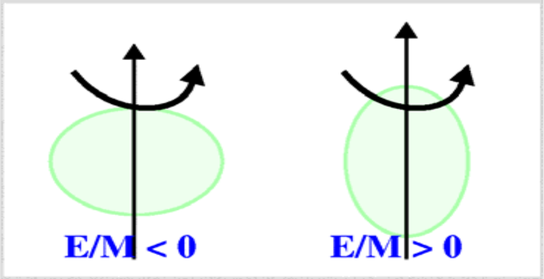
CLAS: ep $\longrightarrow$ epX, E=4GeV



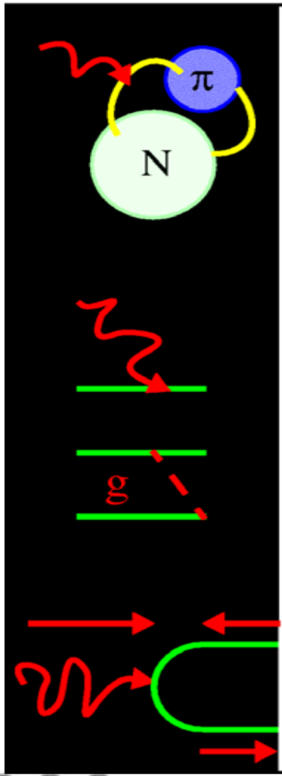
N-Δ(1232) Quadrupole Transition



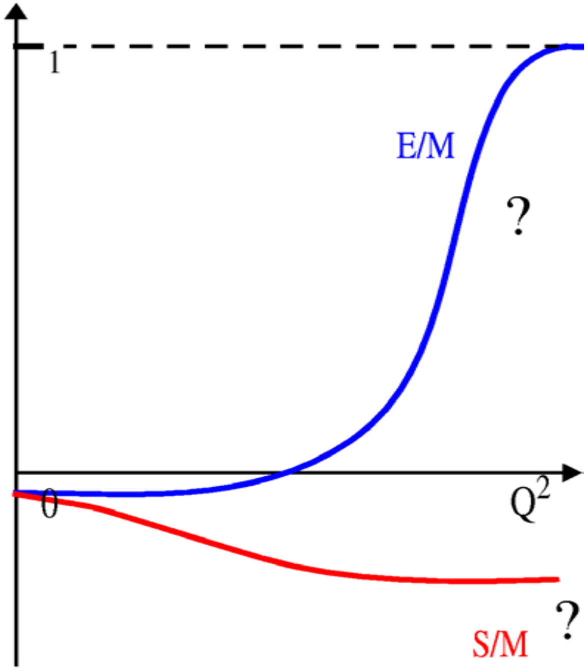
SU(6): $E_{1+}=S_{1+}=0$



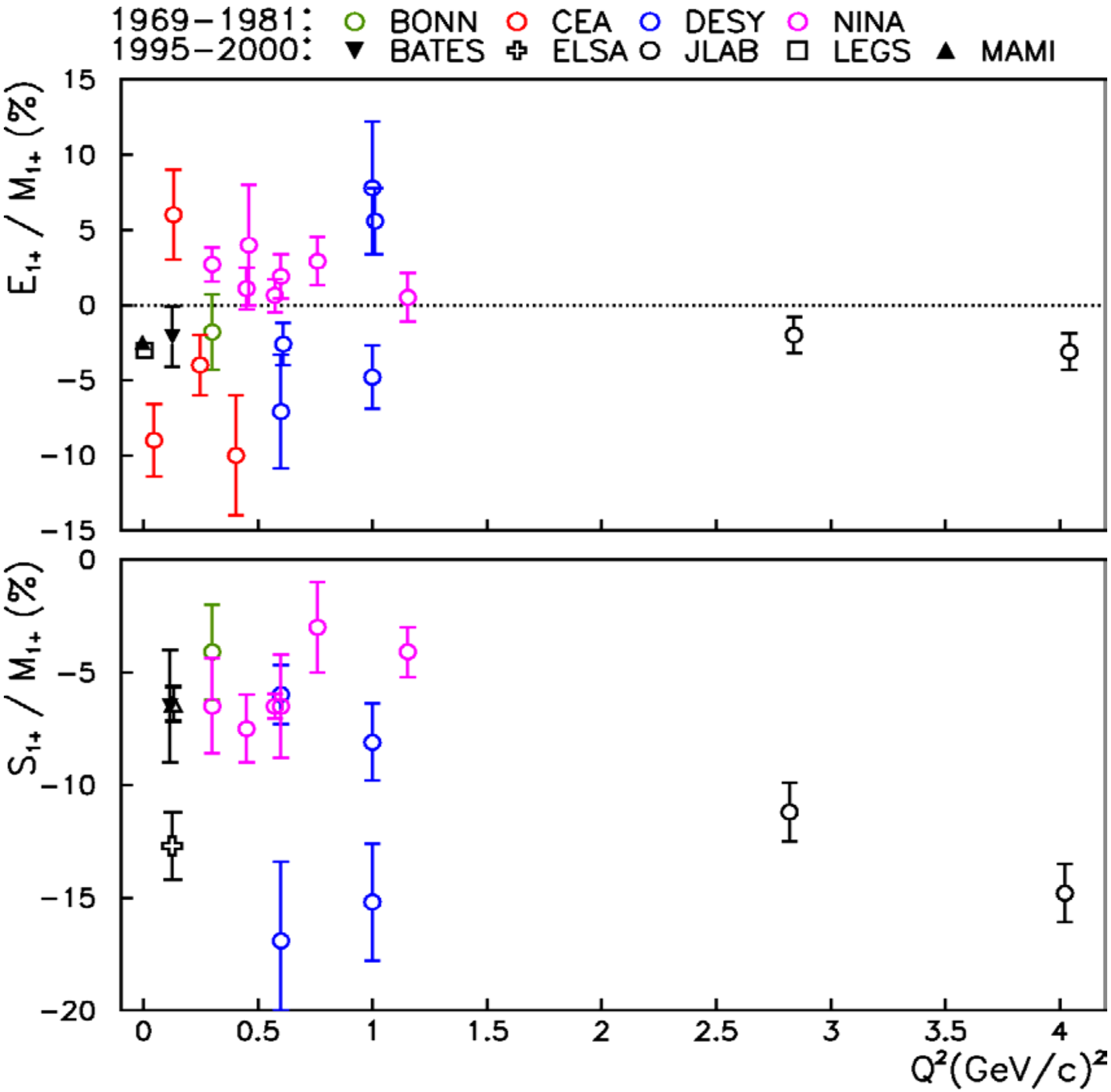
(A. Buchmann, E. Henley, 2000)



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

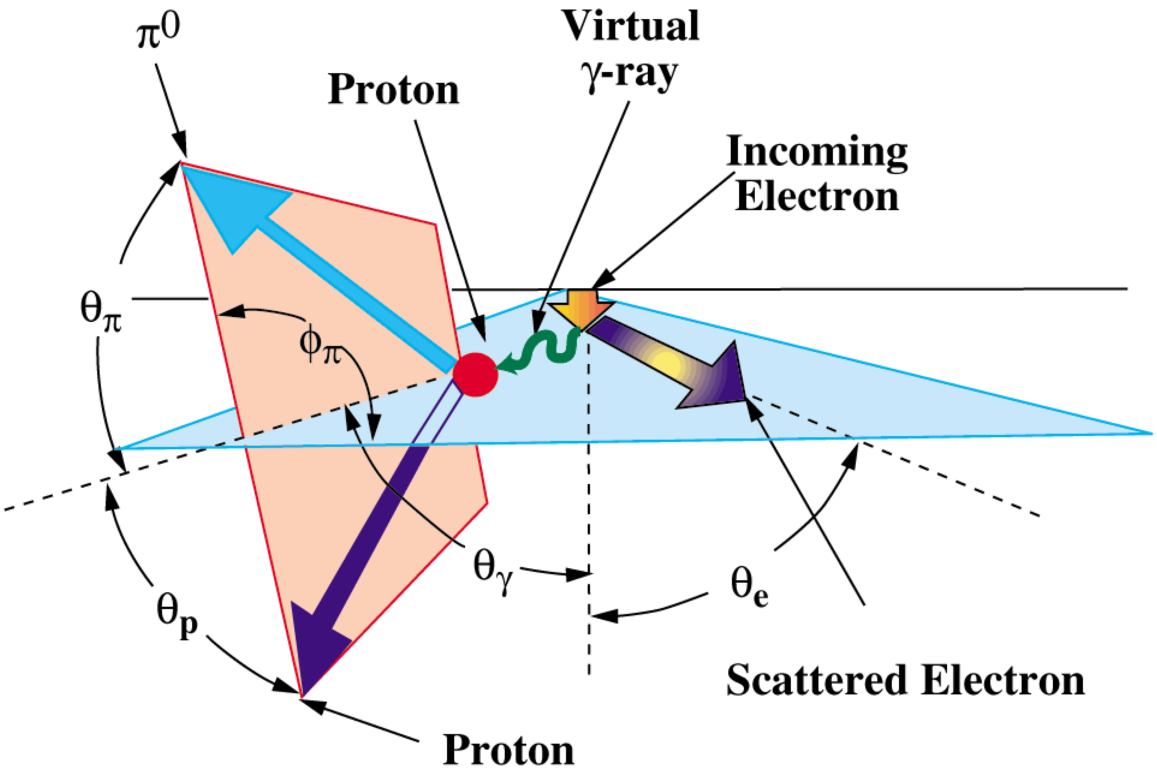


Multipole Ratios R_{EM}, R_{SM} - before 2001



Kinematics for ep → epπ^0

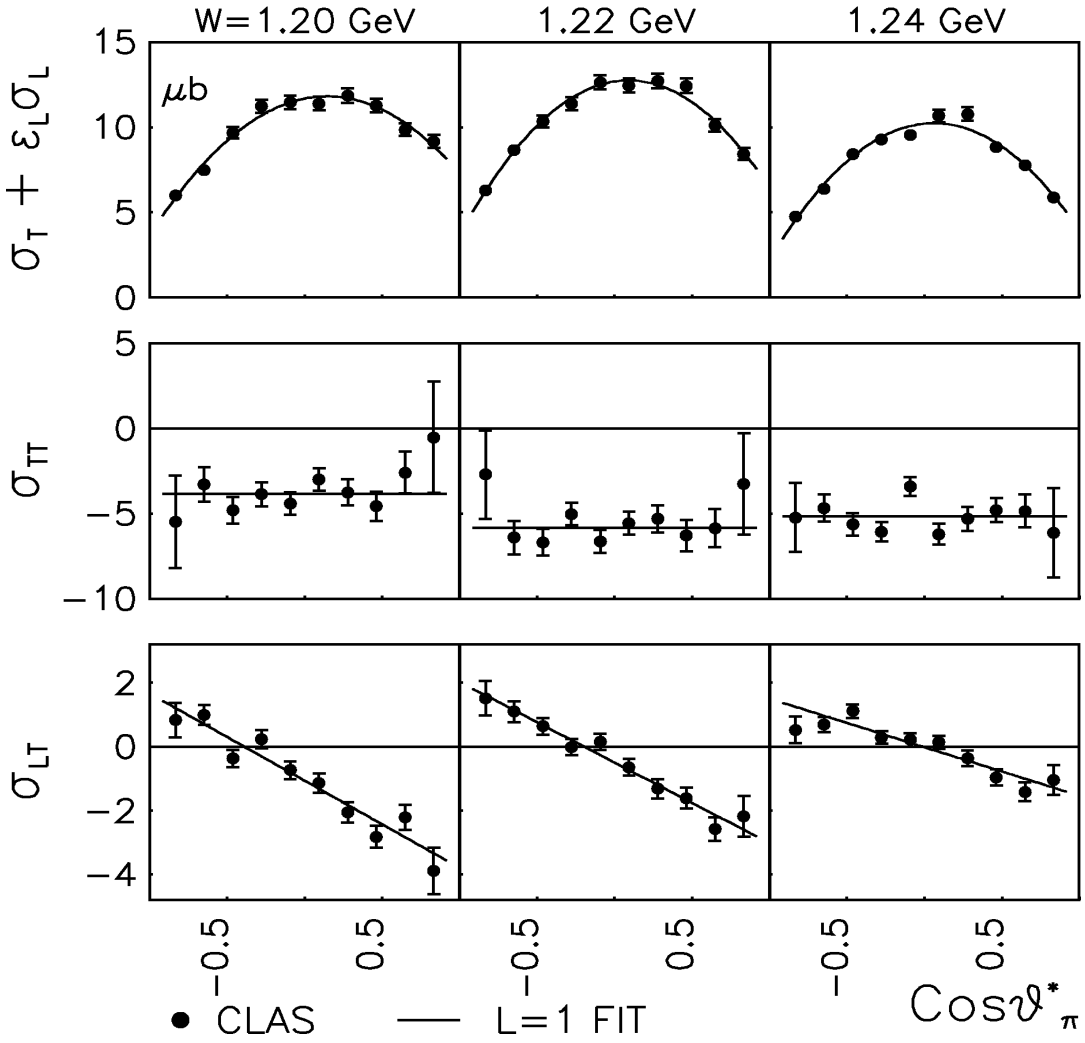
$$\frac{d\,\sigma}{d\Omega_e dE'_e d\Omega_\pi} = \Gamma_t\,(\,\sigma_t + \varepsilon\sigma_l + \varepsilon\sigma_{tt}\cos 2\phi_\pi + \sqrt{2\varepsilon\,(\varepsilon+1)}\;.\;\sigma_{tl}\cos\phi_\pi)$$



Drawings:V.Burkert/Kinematics for epepπ0:MBS

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

CLAS



$Q^2 = 0.9$ GeV^2

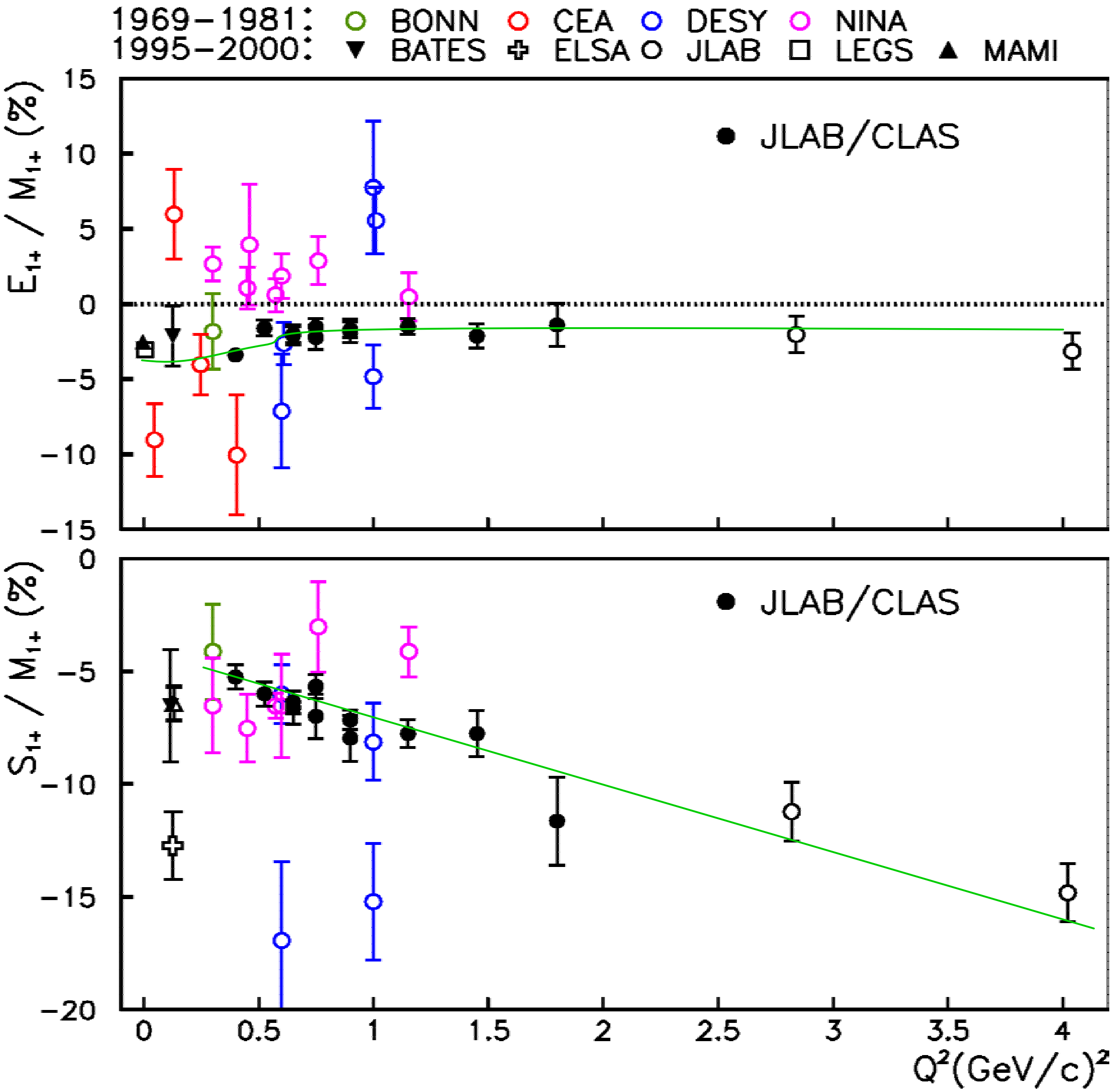
$|M_{1+}|^2$

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

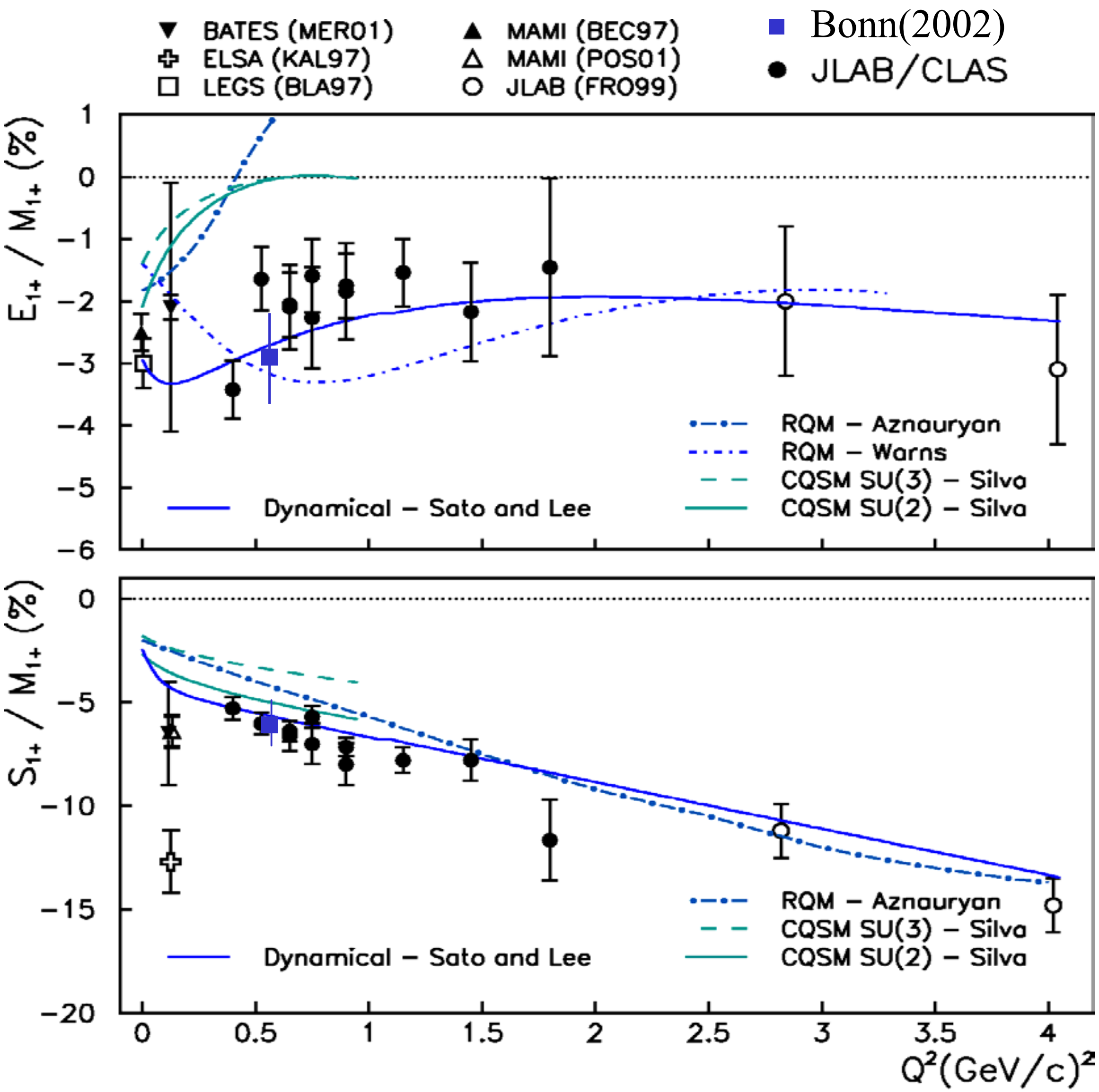
$Re(S_{1+}M_{1+}^*)$

→ ***L.C. Smith***

Multipole Ratios R_{EM}, R_{SM} - 2002



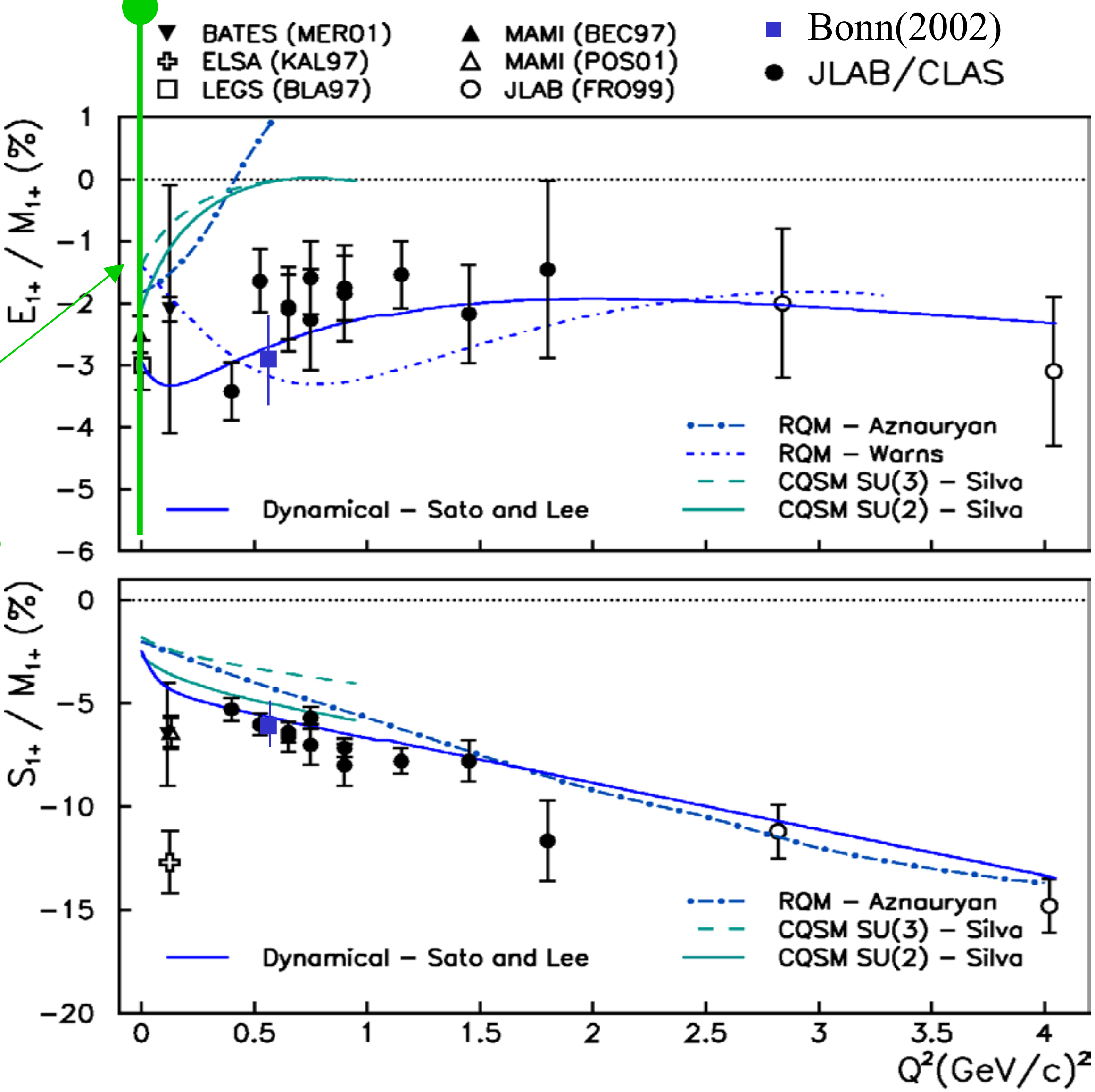
Multipole Ratios $R_{EM}(Q^2)$, $R_{SM}(Q^2)$



→ ***Sato***

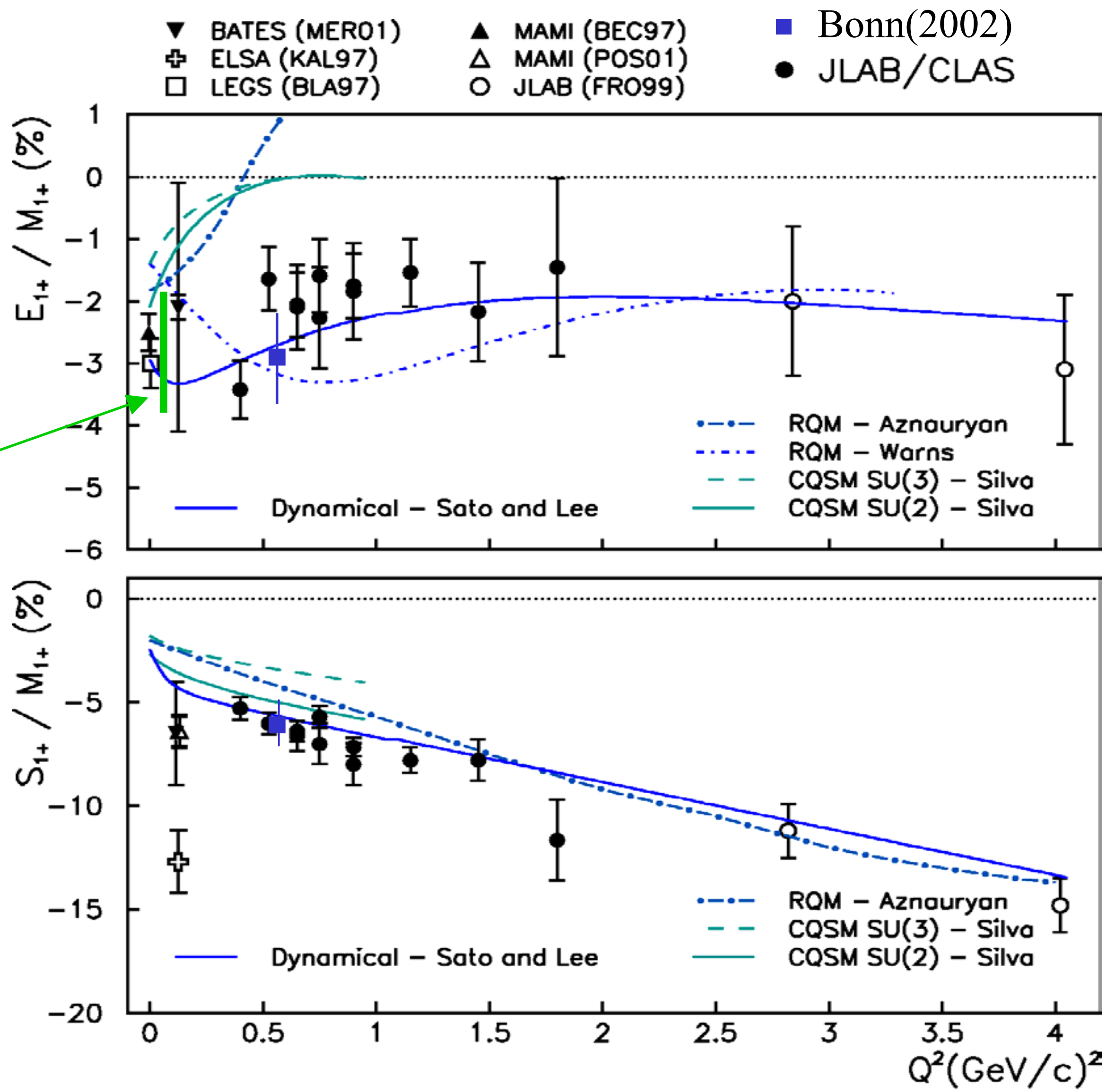
→ ***Ernst***

Multipole Ratios $R_{EM}(Q^2)$, $R_{SM}(Q^2)$



LQCD 1993

Multipole Ratios $R_{EM}(Q^2)$, $R_{SM}(Q^2)$



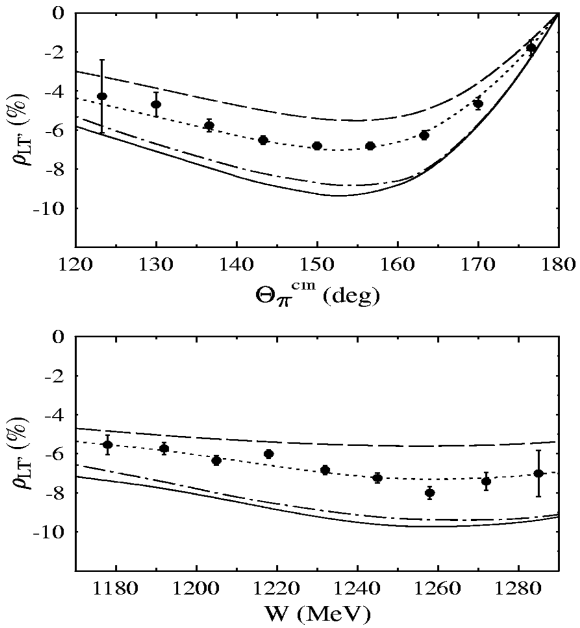
LQCD 2002?

(Moore's law)

Polarized Beam Observable

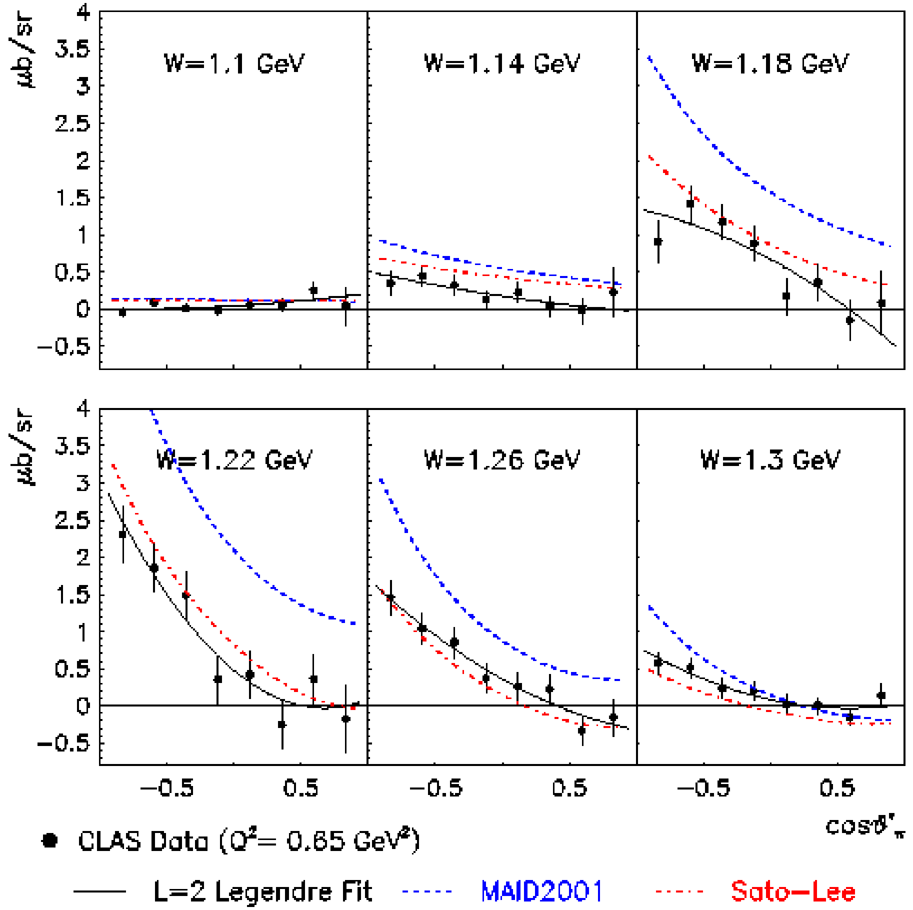
$\vec{e}p \longrightarrow ep\pi^o$ $\sigma_{lt'}$ response function / ***CLAS***

Beam spin asymmetry



Mami/A2

Joo
Botto
Kuhn

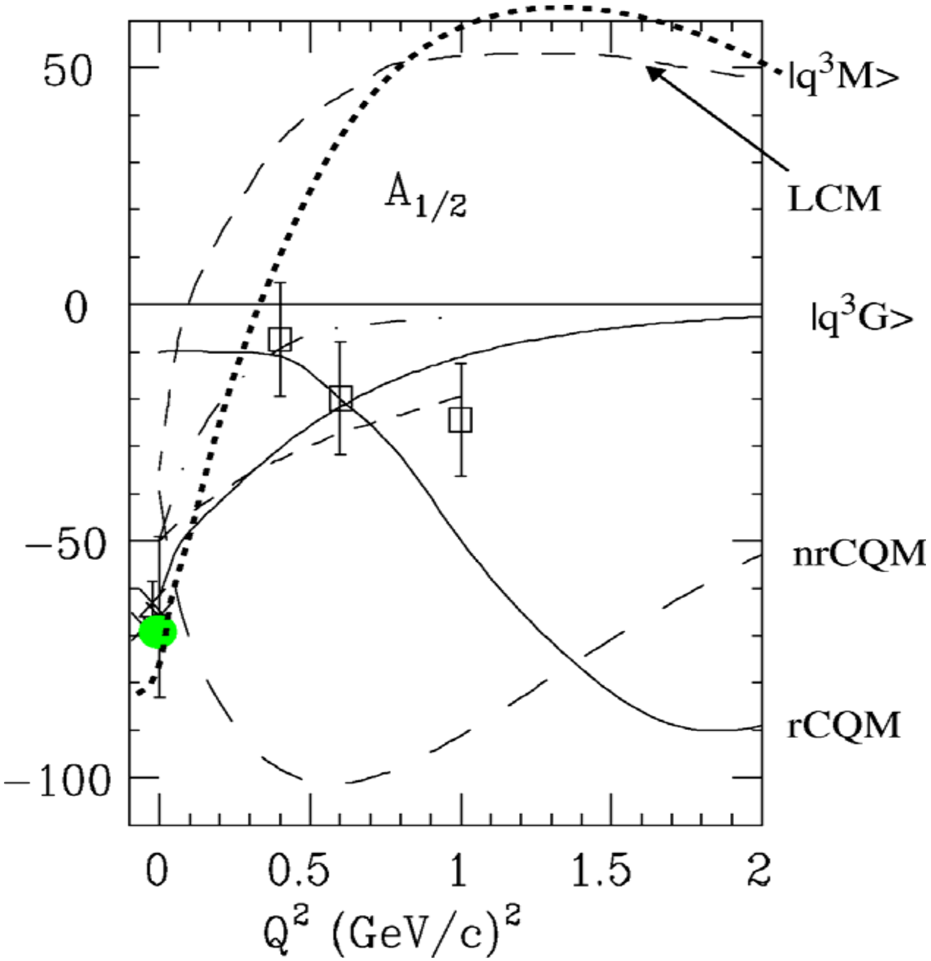


The 2nd Resonance Region

The Roper N’(1440)P_{11}

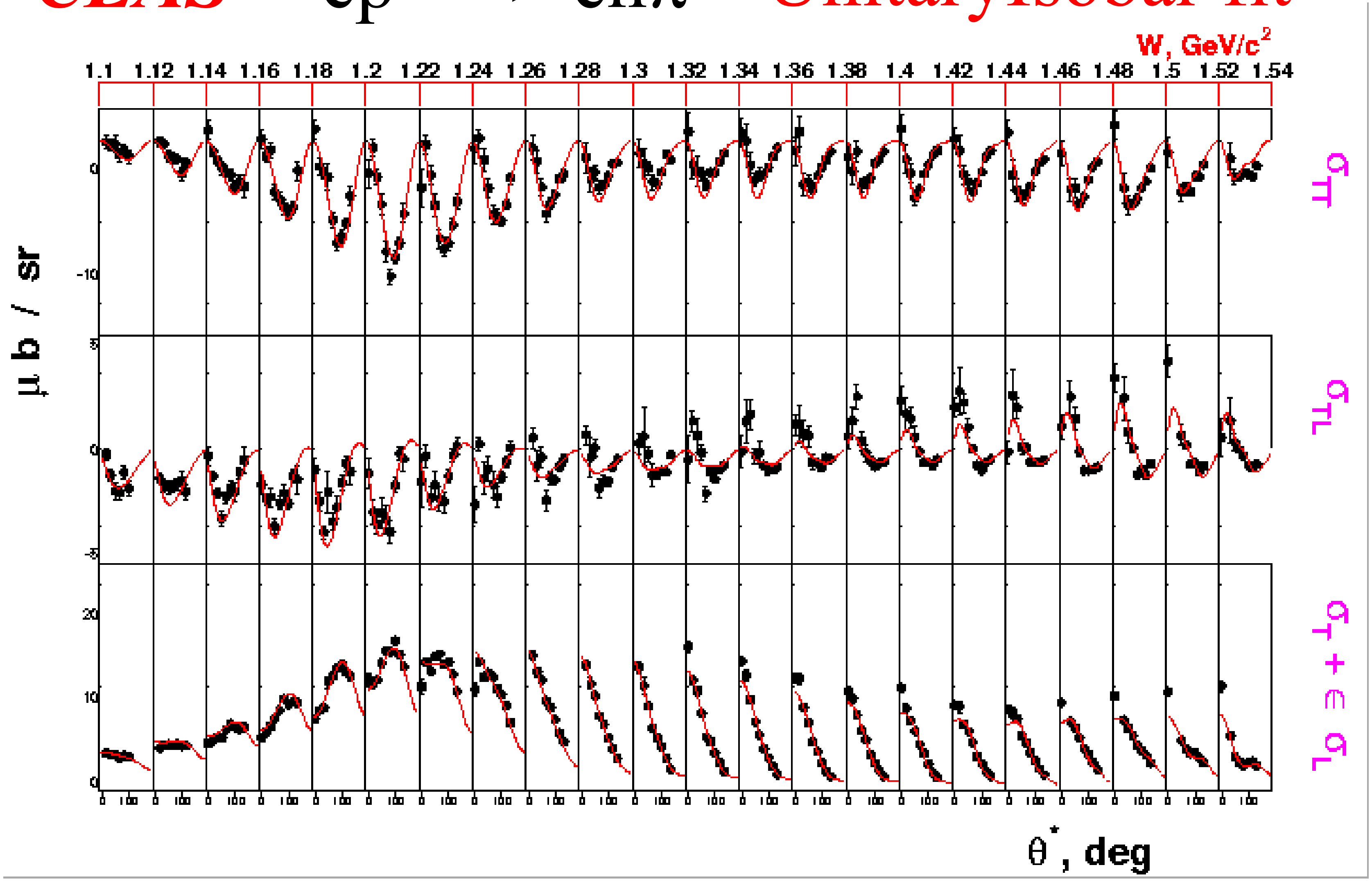
- ❑ In CQM assigned as a N=2 radial excitation of the nucleon
- ❑ Poor description of properties such as mass, photocouplings, Q^2 evolution

> ➢ Strong gluonic component?
>
> ➢ Quark core with meson cloud?
>
> ➢ Nσ molecule?



The 2nd Resonance Region

CLAS ep $\longrightarrow$ enπ^+ UnitaryIsobar fit



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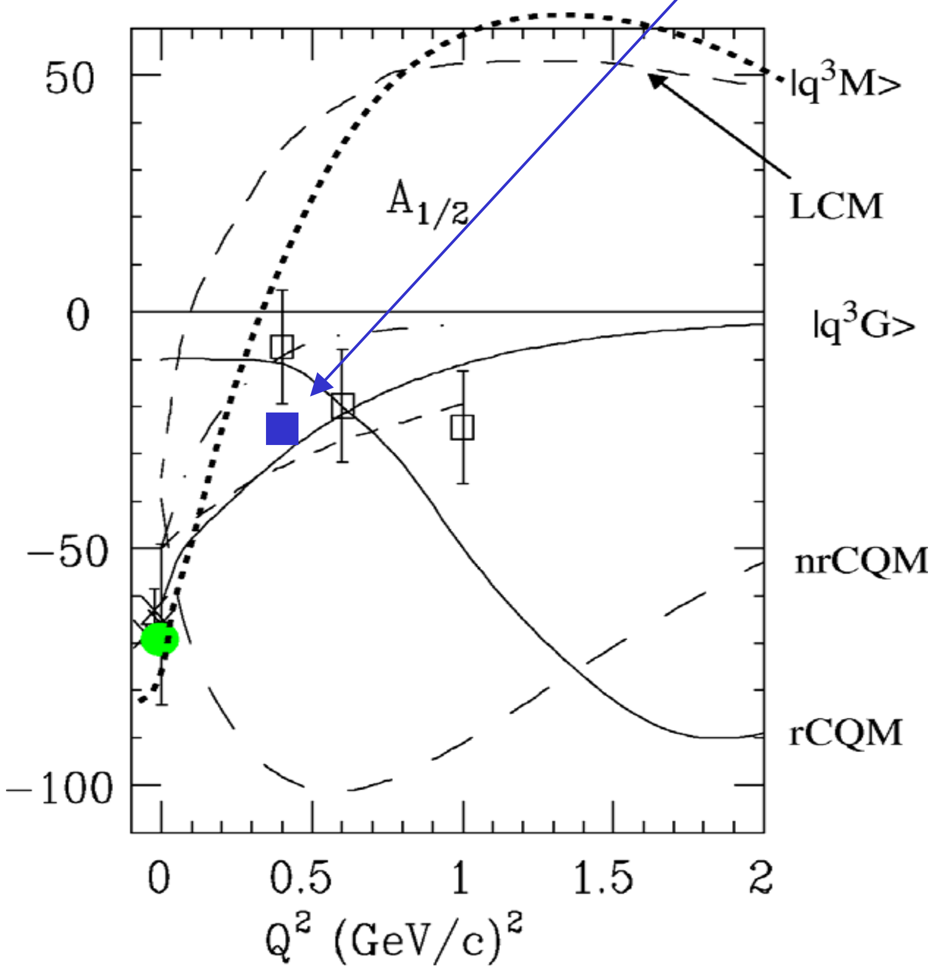
→ ***H. Egiyan***

CLAS (preliminary)

$\sigma(\pi^o,\pi^+)$, $A_e(\pi^o,\pi^+)$, unitary isobar fit

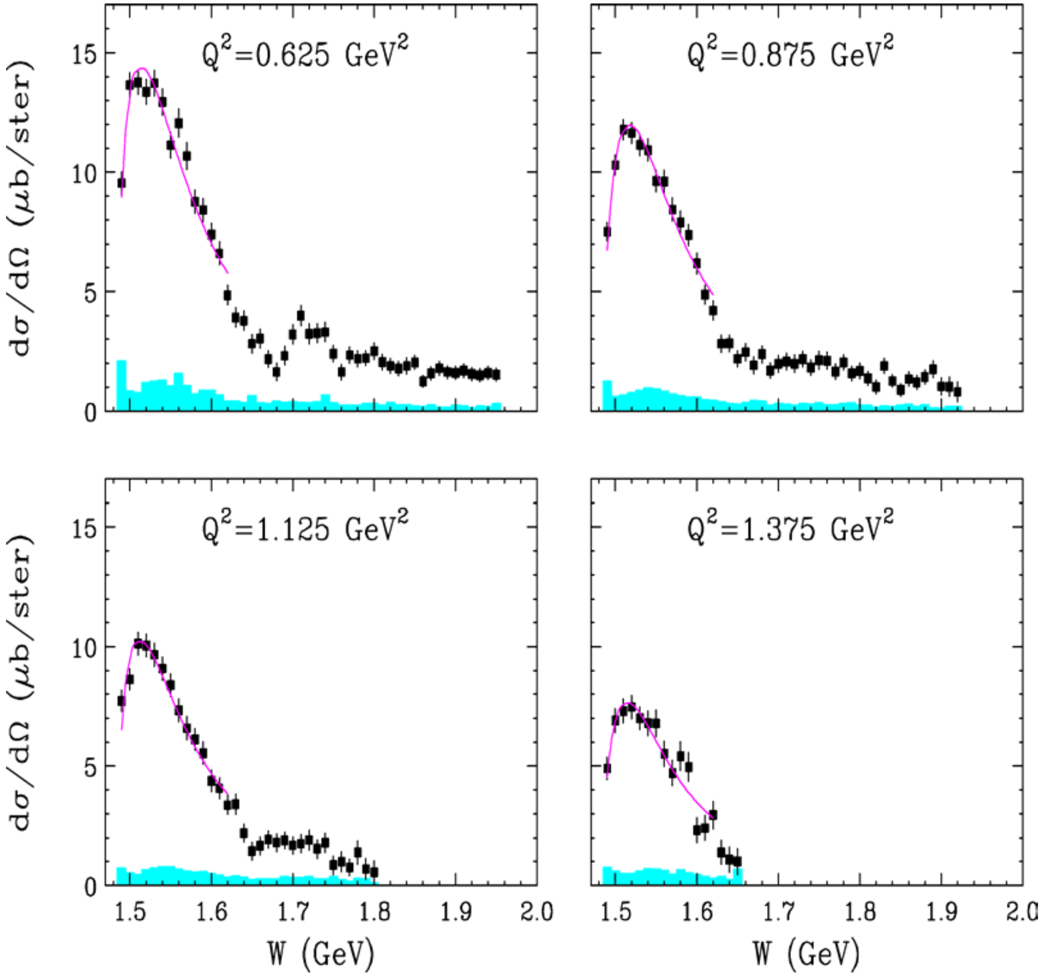


The 2nd Resonance Region

$N^*(1535)S_{11}$

- CQM assigns state to the $[70,1^-]$ multiplet
- Speculation if it is not a $|q^3>$ state but a $|K\Sigma>$ molecule
- Hard e.m. formfactor
- LQCD indicates clear $|q3>$ behavior
- Strong coupling to pη

CLAS $ep \longrightarrow ep\eta$



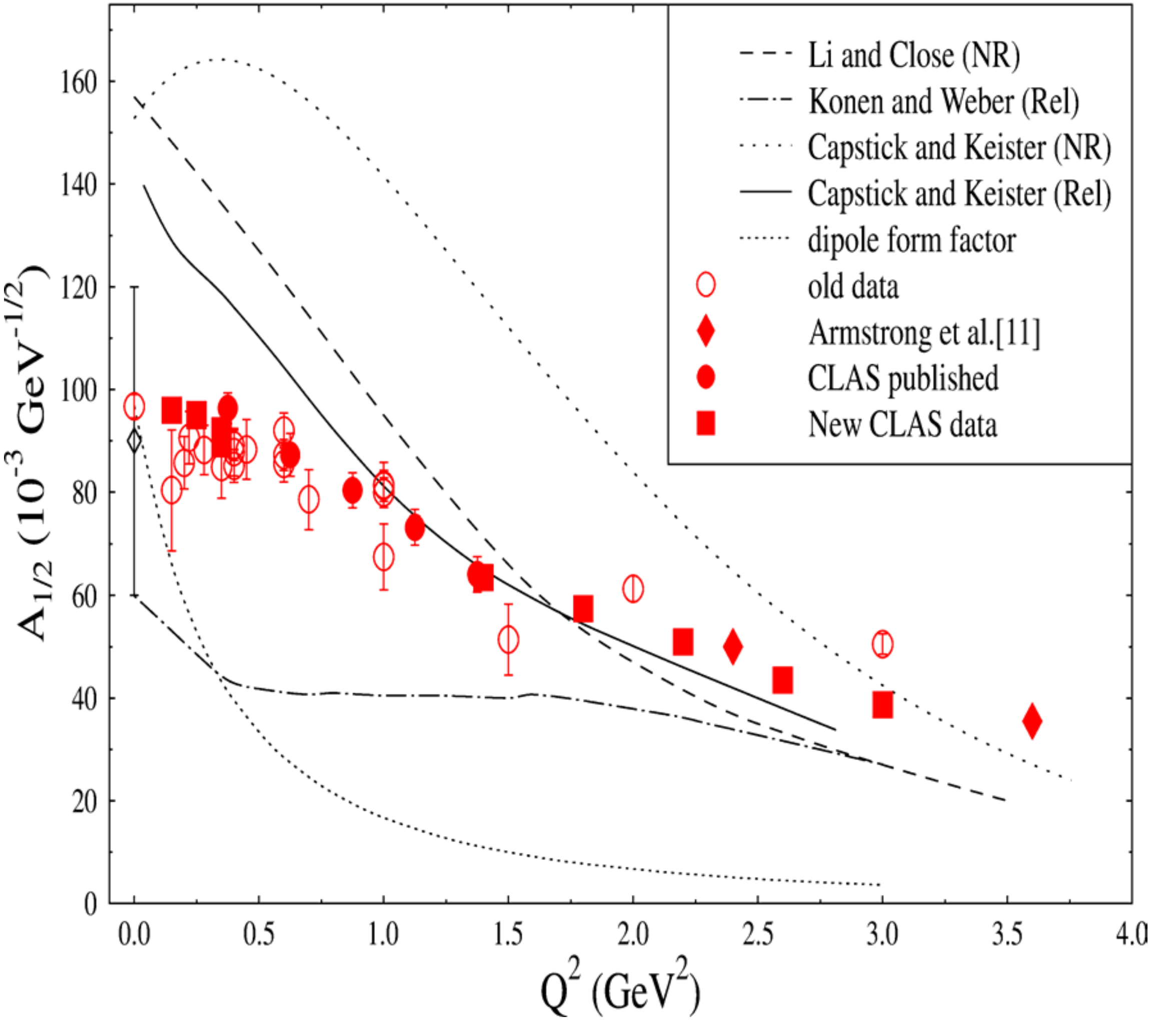
The 2nd Resonance Region

$N^*(1535)S_{11}$

- Consistent Q^2 evolution from η production

→ ***H. Denizli***

Photocoupling amplitude $A_{1/2}$



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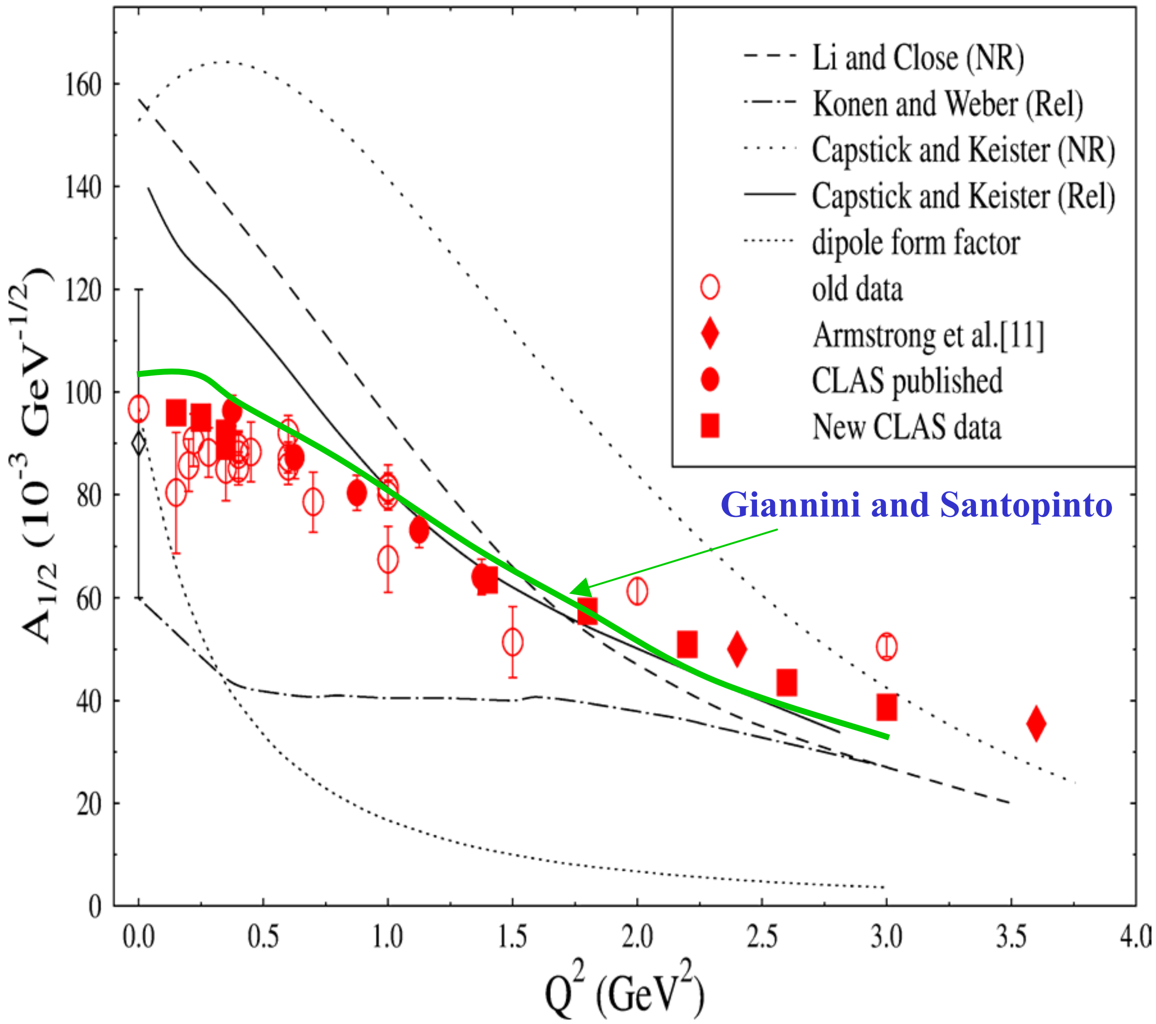


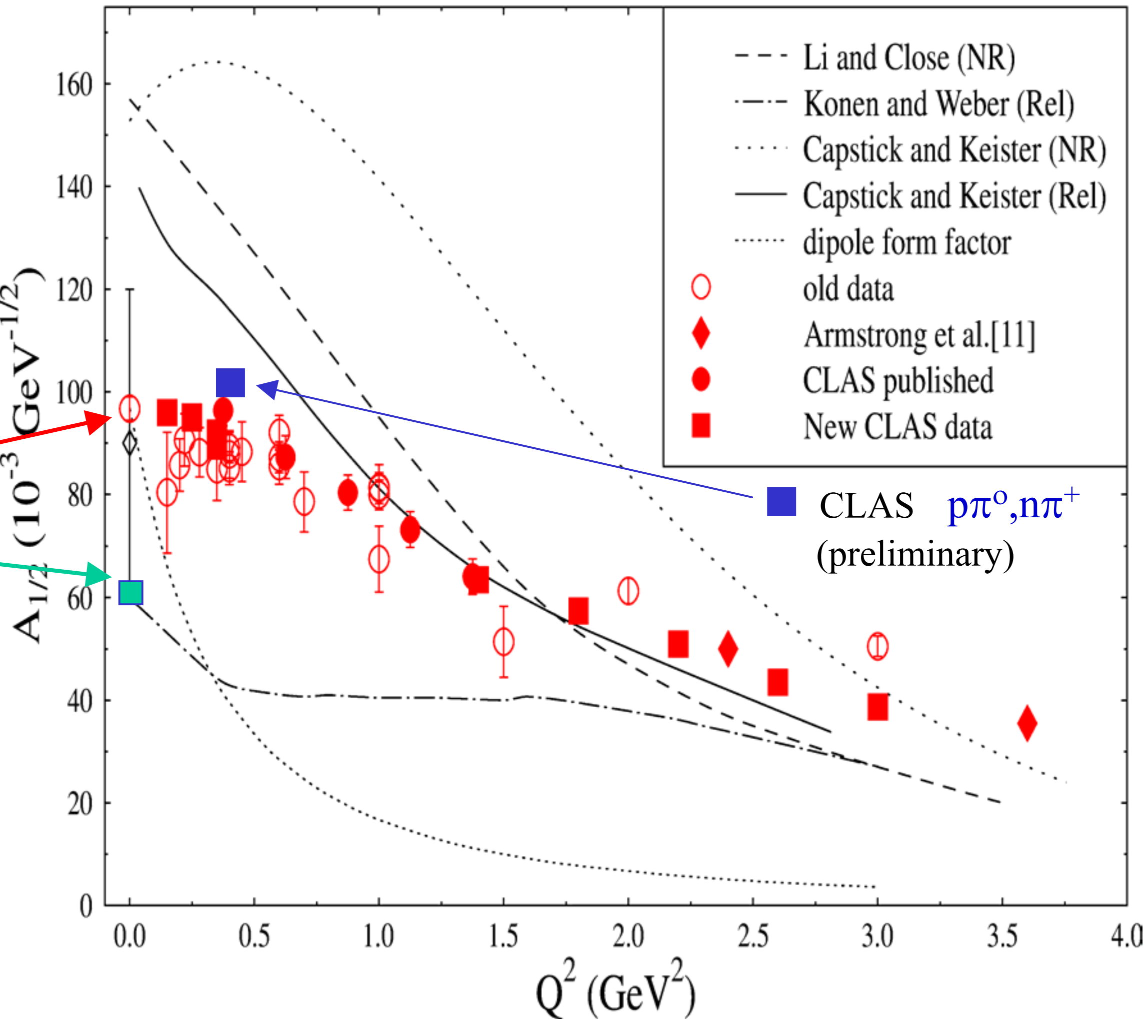
Giannini and Santopinto

The 2nd Resonance Region

$N^*(1535)S_{11}$

- Consistent Q^2 evolution from η production
- Discrepancy with Nπ analysis
- ***CLAS*** pη and Nπ data consistent

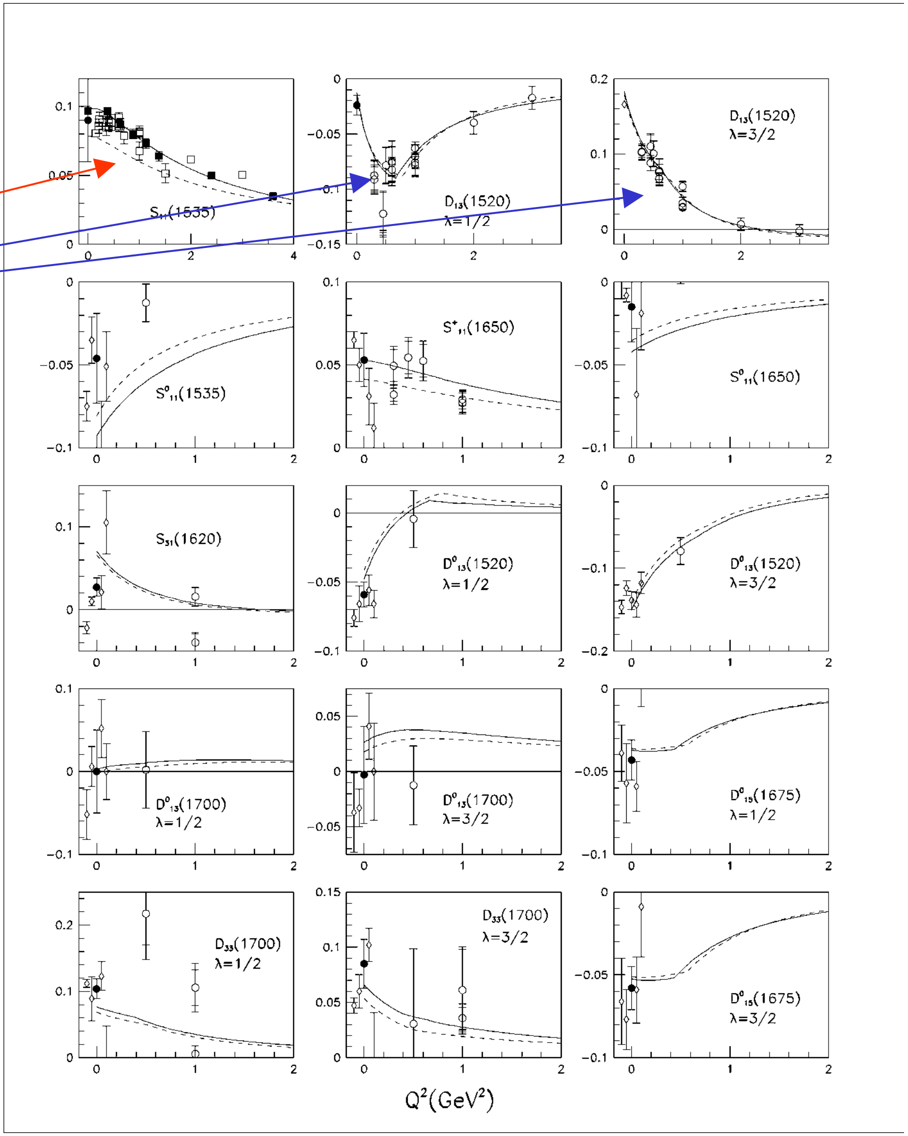
Photocoupling amplitude $A_{1/2}$



CLAS $p\pi^o, n\pi^+$
(preliminary)

Single Quark Transition Model

- Transition [56,0$^+$] -> [70,1$^-$] described by 3 amplitudes, e.g. determined from S_{11}, D_{13}



Single Quark Transition Model

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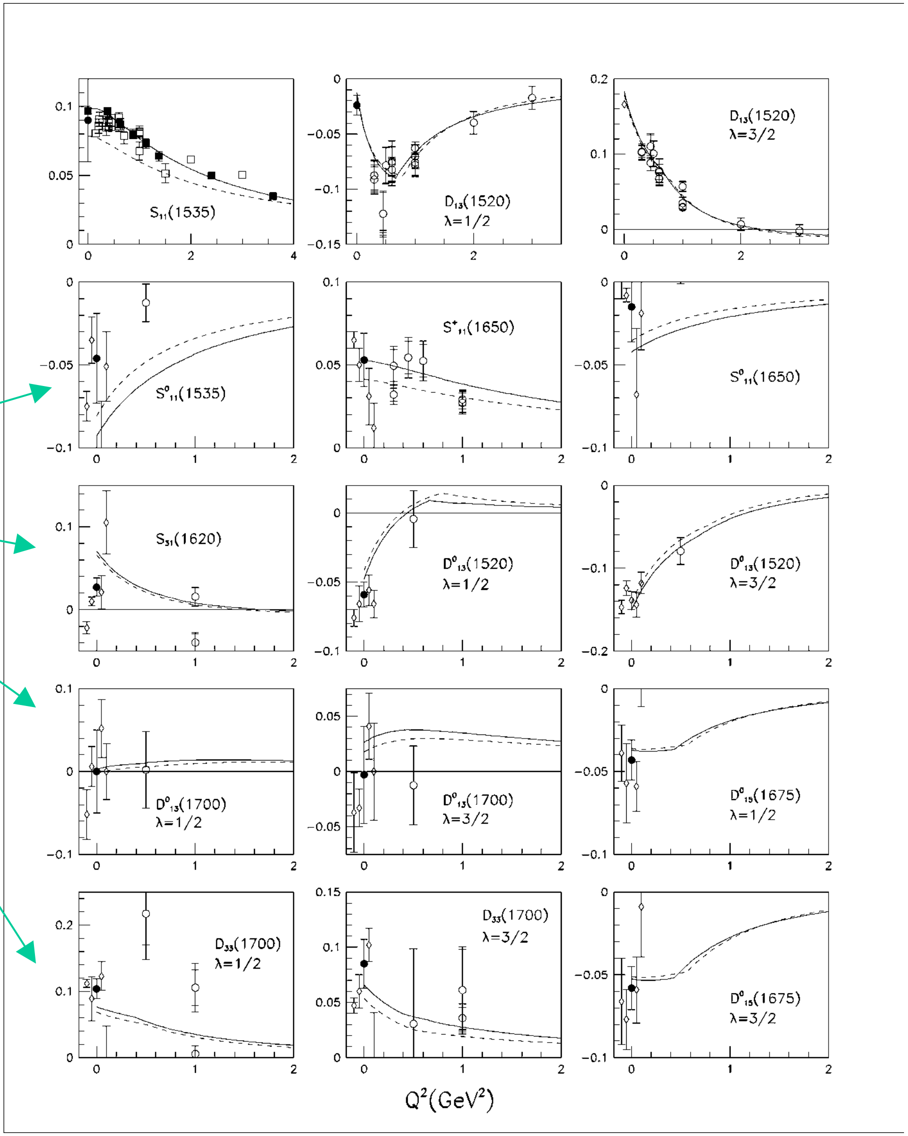
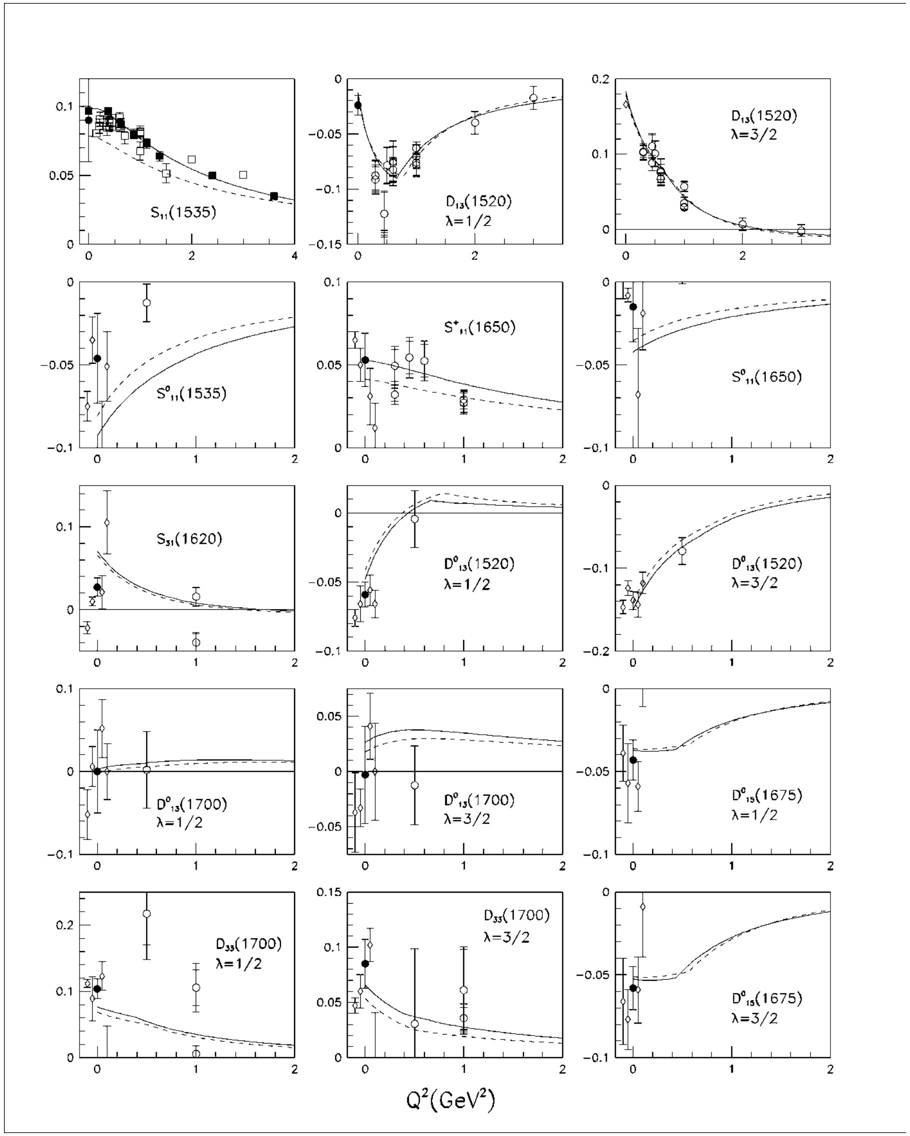
- Predicts all other amplitudes in same supermultiplet



Test of the Single Quark Transition Model

- Transition $[56,0^+]$ -> $[70,1^-]$ described by 3 amplitudes, e.g. determined from S_{11}, D_{13}
- Predicts all other amplitudes in same supermultiplet
- Tests model in the large N_c limit
- Good description of $Q^2=0$
- Insufficient $Q^2 \neq 0$ data

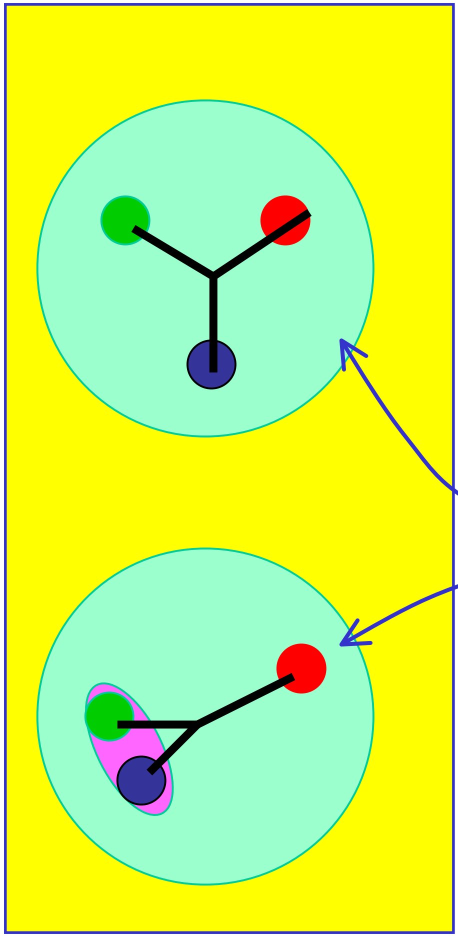


Higher mass and “missing states”

- Higher mass states tend to couple strongly to Nππ

State	πN	ηN	πN wave	ππN
$N_{1/2-}(1535)$	40	45	S_{11}	5
$N_{1/2+}(1440)$	65		P_{11}	35
$N_{1/2+}(1710)$	15		P_{11}	40 - 90
$N_{3/2+}(1720)$	15		P_{13}	70
$N_{3/2-}(1520)$	55		D_{13}	45
$N_{3/2-}(1700)$	10		D_{13}	90
$N_{5/2-}(1675)$	45		D_{15}	55
$N_{5/2+}(1680)$	65		F_{15}	35
$\Delta_{1/2-}(1620)$	25	-	S_{31}	75
$\Delta_{3/2+}(1232)$	100	-	P_{33}	
$\Delta_{3/2+}(1600)$	15	-	P_{33}	~80
$\Delta_{3/2-}(1700)$	15	-	D_{33}	85
$\Delta_{7/2+}(1950)$	40	-	F_{37}	35

“Missing” Resonances?



- ☐ Symmetric CQM predicts many more states than observed in elastic πN scattering analysis

$|q^3>$ => predicted to couple to
Nππ (Δπ, Nρ), Nω, KY

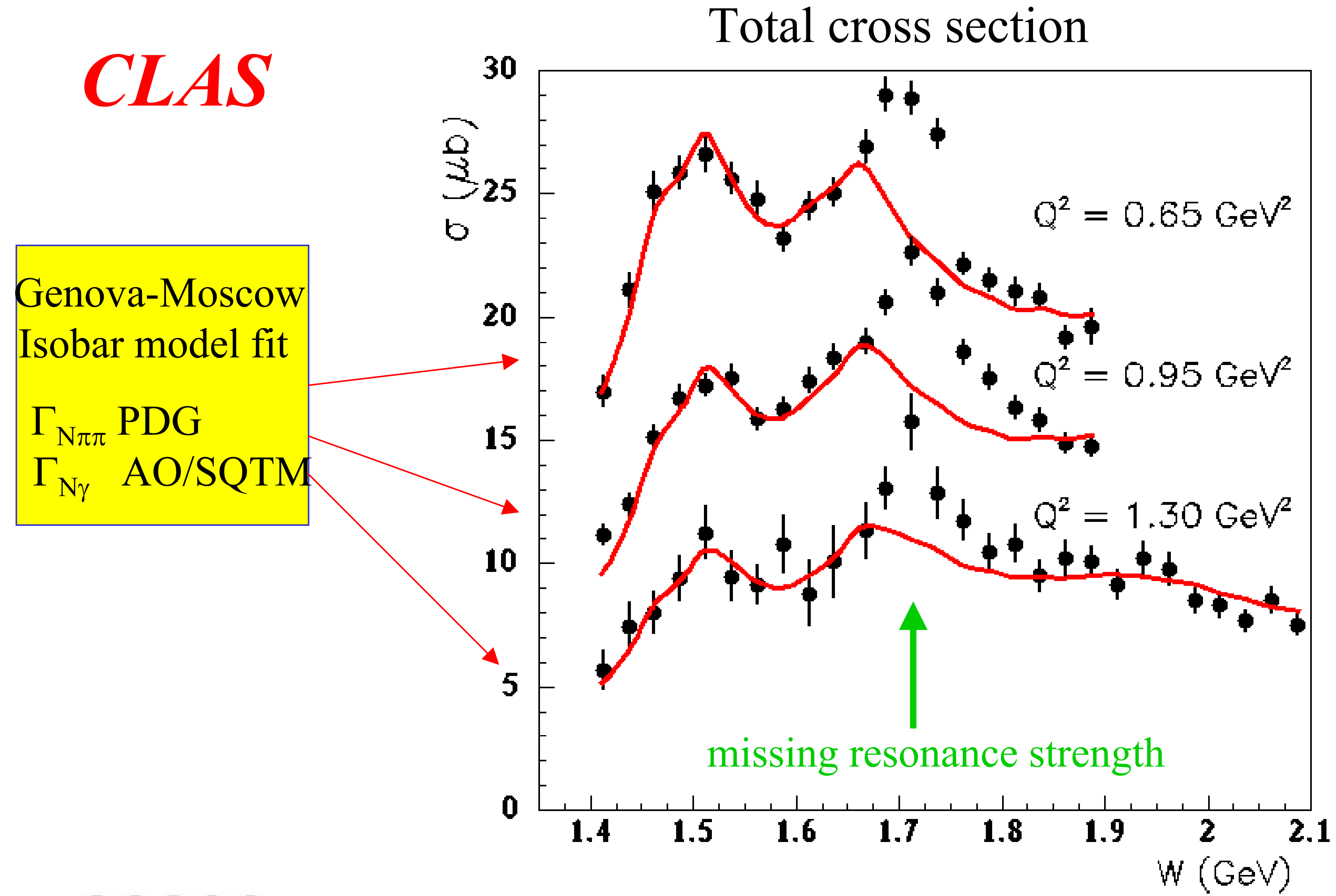
which model is closer to reality?

$|q^2q>$ => fever excitation degrees of freedom
fewer states

→ ***Klempt, Vijande***

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

CLAS



Genova-Moscow
Isobar model fit

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

Total cross section

missing resonance strength

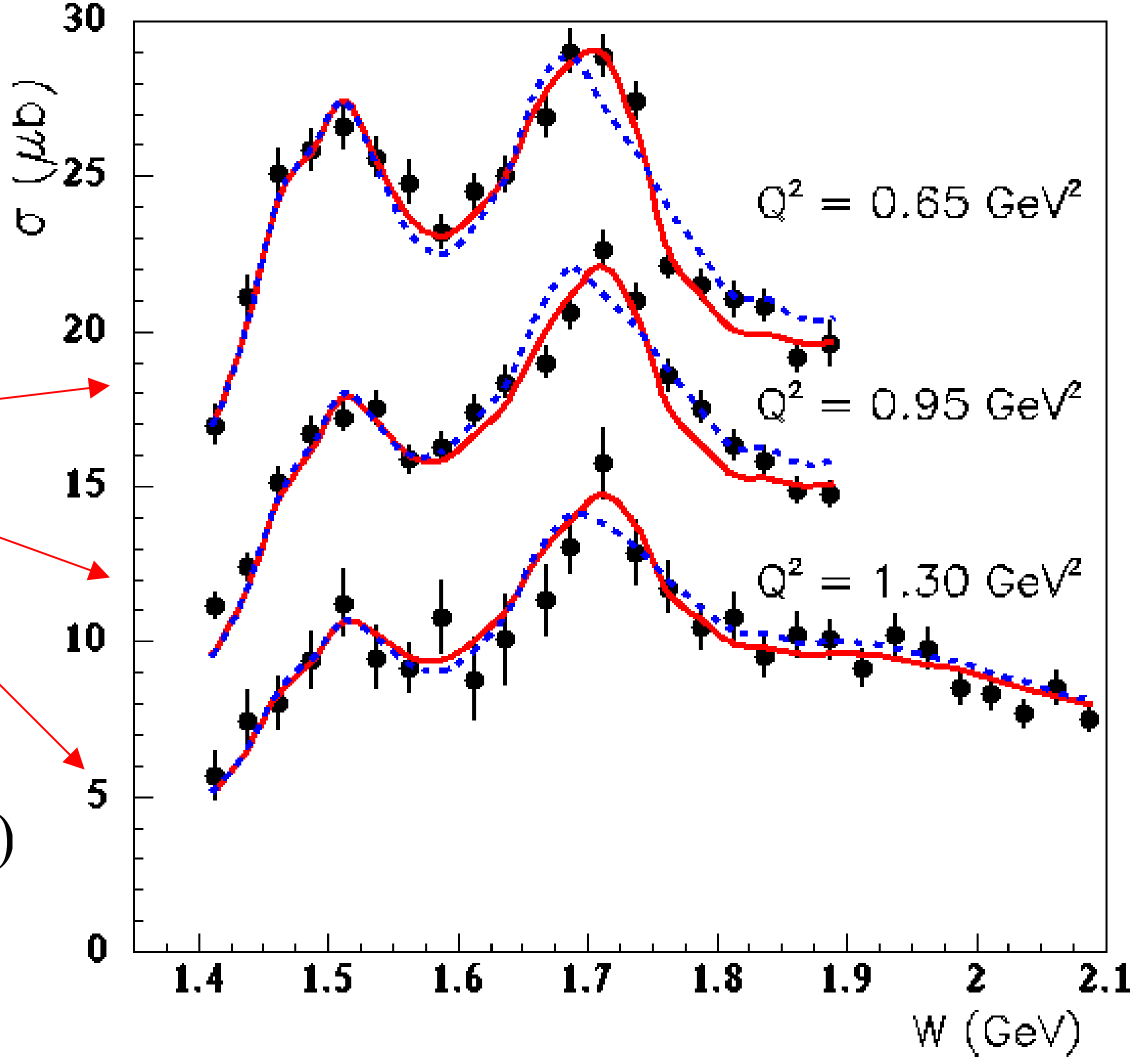
Isobar fit to $D_{13}(1700)$ and new P_{13}

CLAS

Genova-Moscow
Isobar model fit

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

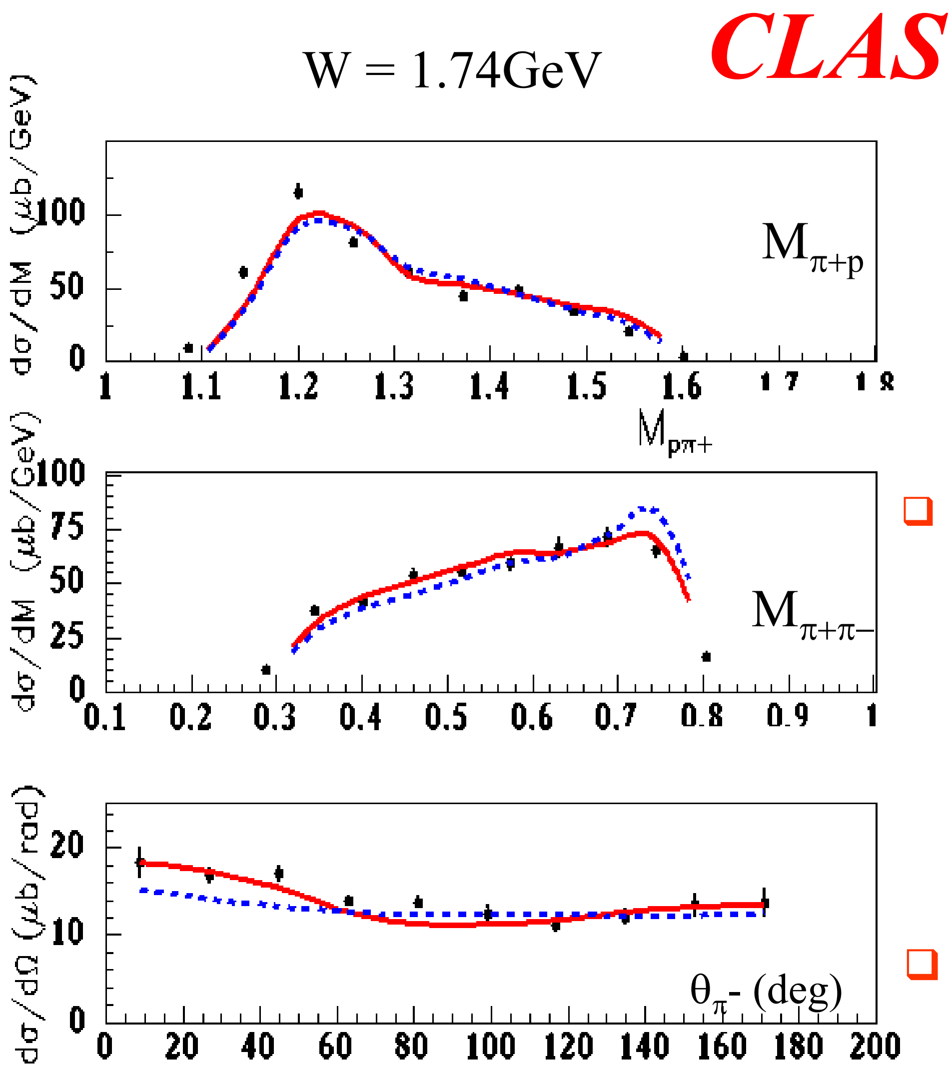
Total cross section



——— P_{13}

- - - - - $D_{13}(1700)$

Isobar fit - A new state?



- ☐ Data described best by new P_{13}

M = 1.72 +/- 0.02 GeV	1650-1750
Γ_T = 88 +/- 17 MeV	100-200
$\Delta\pi$: 0.41 +/- 0.13	~ 0
$N\rho$: 0.17 +/- 0.10	0.8 - 0.9
	known P_{13}

- ☐ consistent with "missing" P_{13} state, but mass low

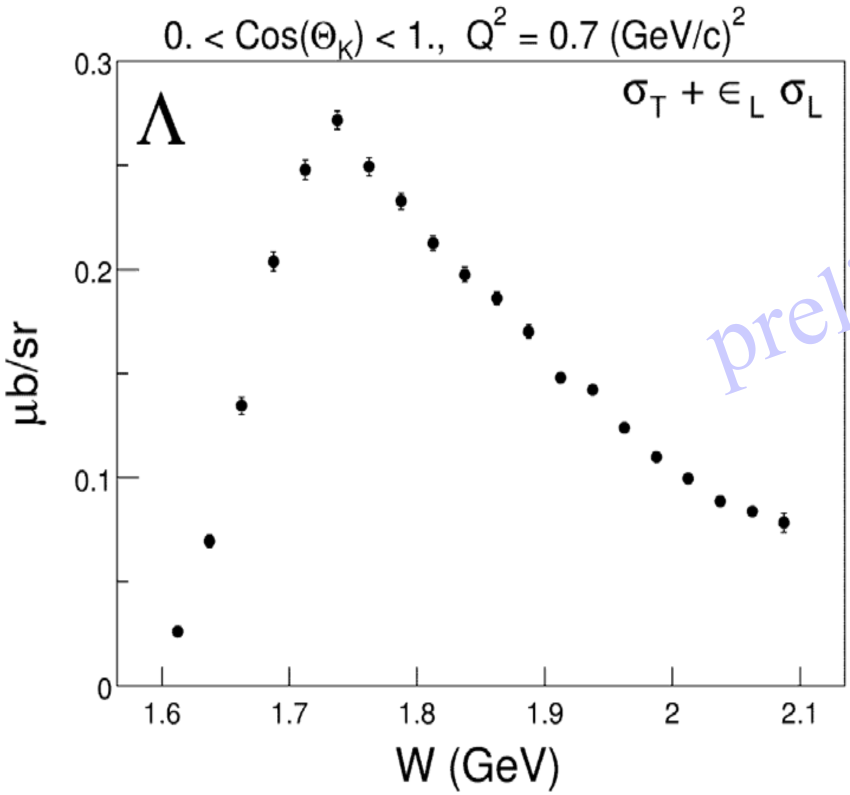
→ ***F. Klein***

Search for resonances in hyperon production

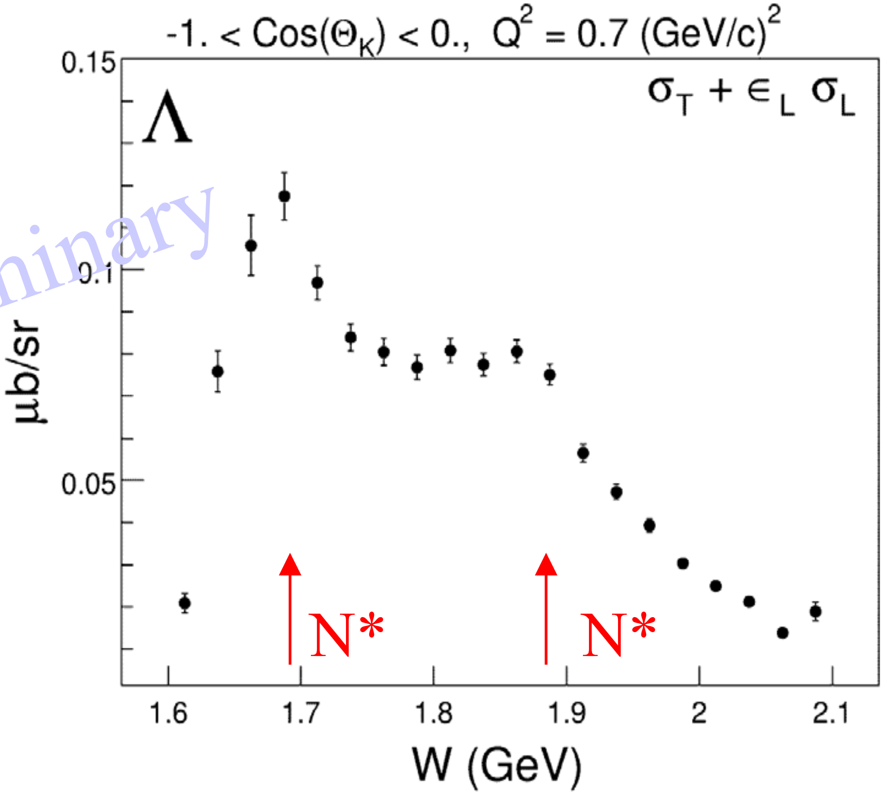
CLAS

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

forward hemisphere

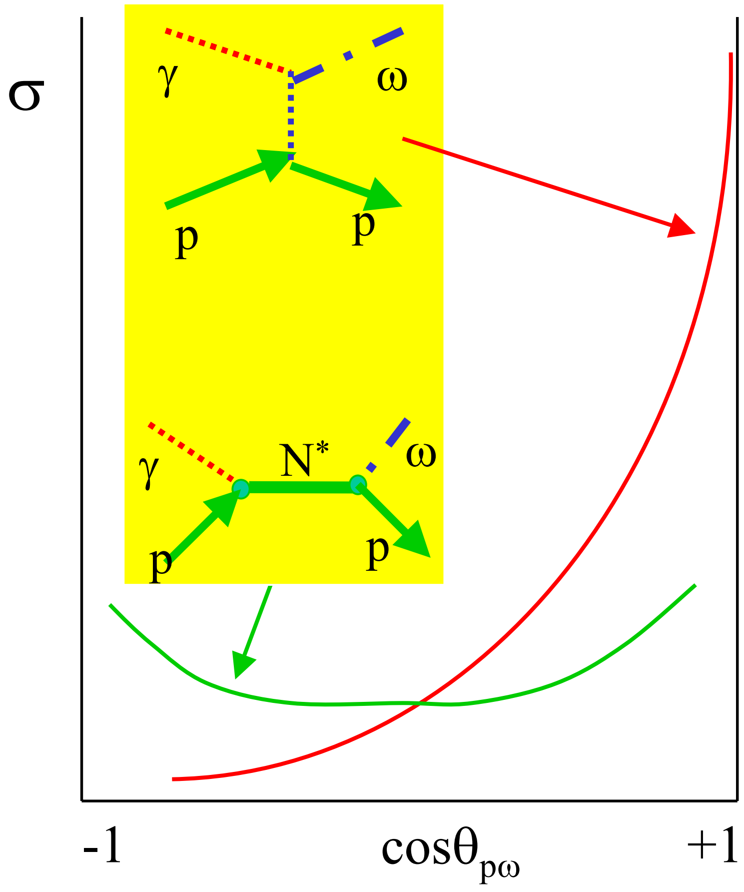


backward hemishere

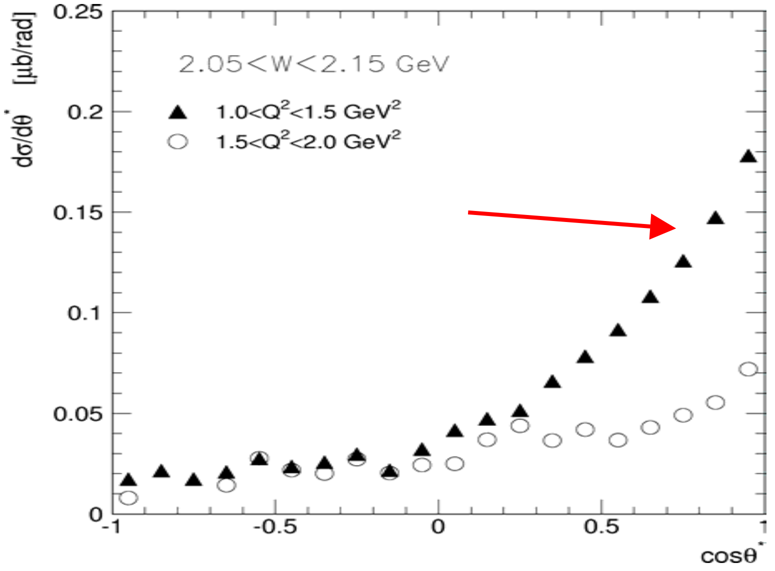


→ ***Niculescu/Feuerbach***

Resonances in $\gamma^* p \longrightarrow p\omega$?

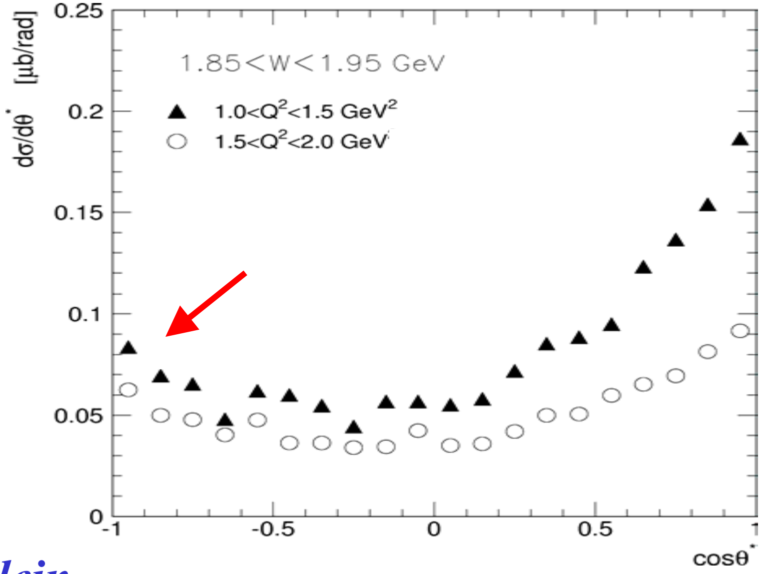


above resonance region



CLAS

in resonance region



→ ***F. Klein***

Resonances in Virtual Compton Scattering

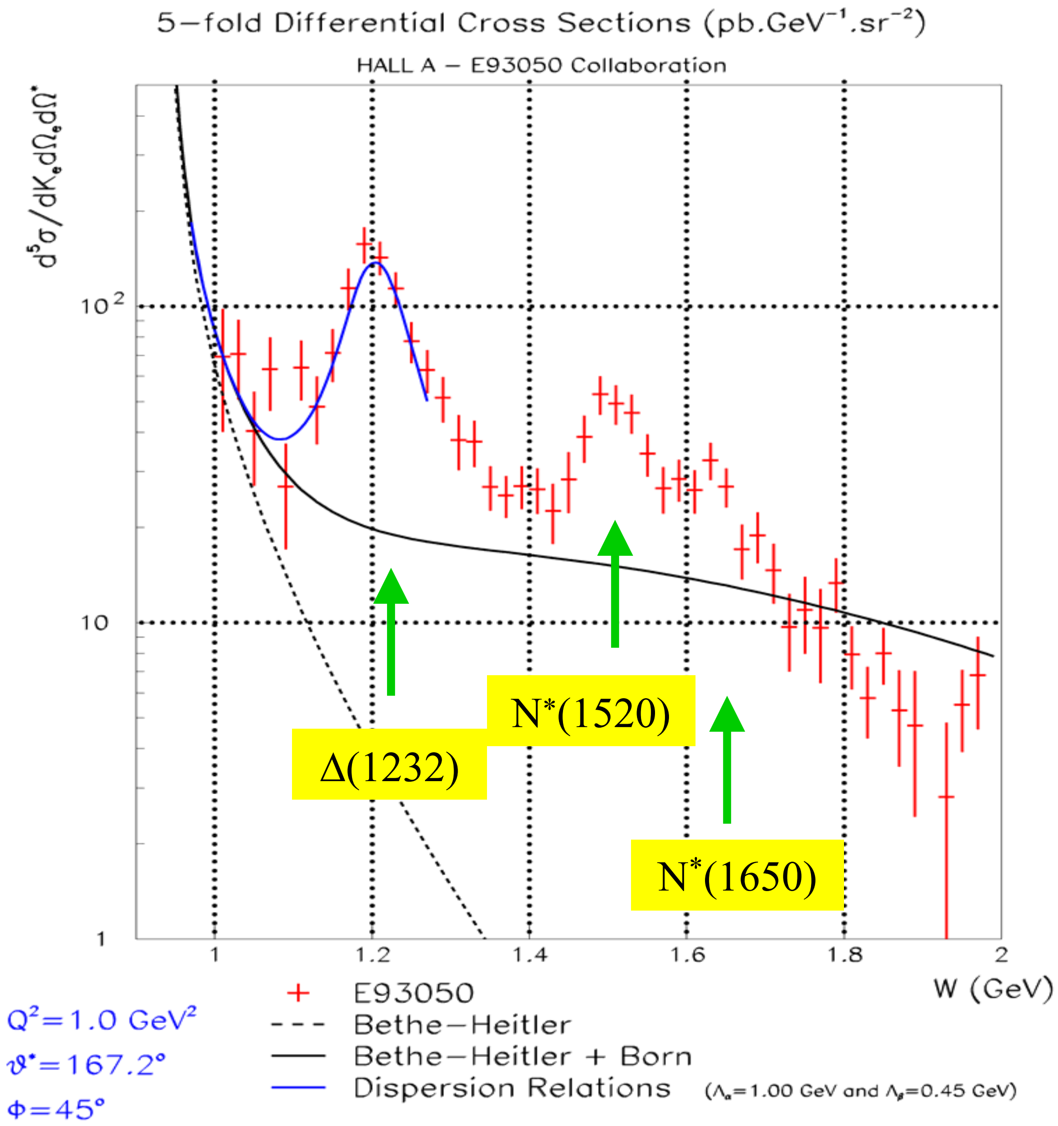
Hall A - E93-50

$$ep \longrightarrow ep\gamma$$

- First measurement through entire resonance region
- advantage over mesons, the lack of final state interaction
- strong resonance excitations

→ ***Fonvieille***

→ ***Todor***



Summary

- Accurate results on transition amplitudes for several states give a consistent picture, and allow stringent test of theory
  - Δ(1232), N^*(1535), (Roper)
- Searches in various final states suggest excitations of states not seen before
  - $p\pi^+\pi^-$, $p\omega$, $K^+\Lambda$, ...
- N* electroexcitation has become a major tool in studying the complex regime of strong QCD and confinement

Outlook

- ☐ Transition amplitudes for several states under study CLAS, Hall A/C, OOPS

- ☐ New instrumentation/facilities - BLAST, MAMI upgrade

- ☐ The Δ(1232) is the only resonance so far seen first in electron scattering experiments.

Perhaps, this long drought is over soon.

The potential is there!

It is an exciting time to work in this field !