Electroexcitation of Nucleon Resonances

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Jefferson Lab

BARYONS '02

9th International Conference on the Structure of Baryons

March 3 - 8, 2002

Why N*'s are important

(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"

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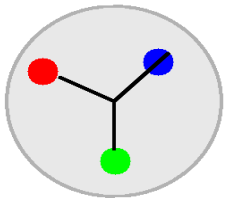
  "the non-abelian character of QCD is manifest"

symbol of BARYONS 2001



3-gluon vertex

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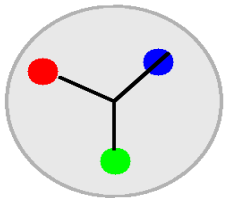


3-gluon vertex

- 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?

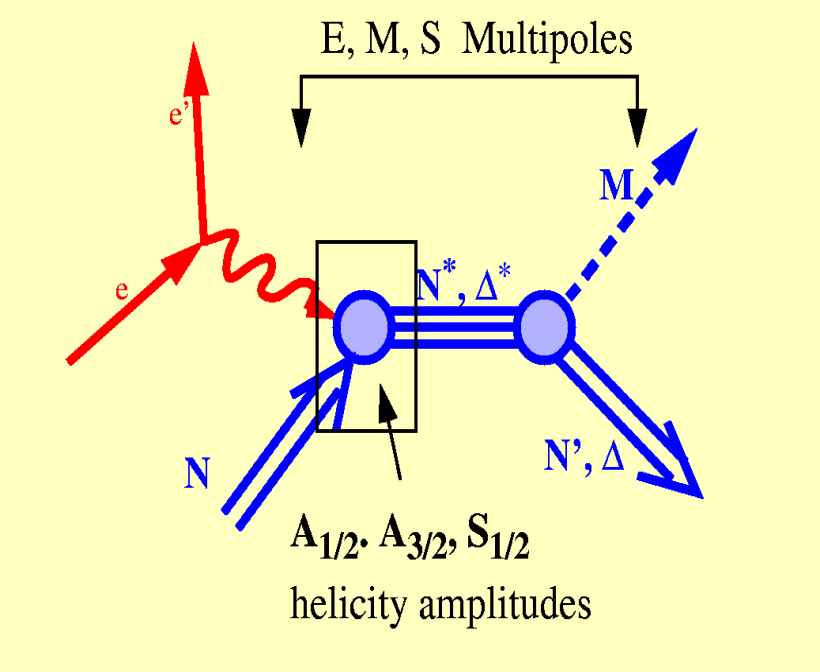
- Summary/Outlook

Why N* Electroproduction?

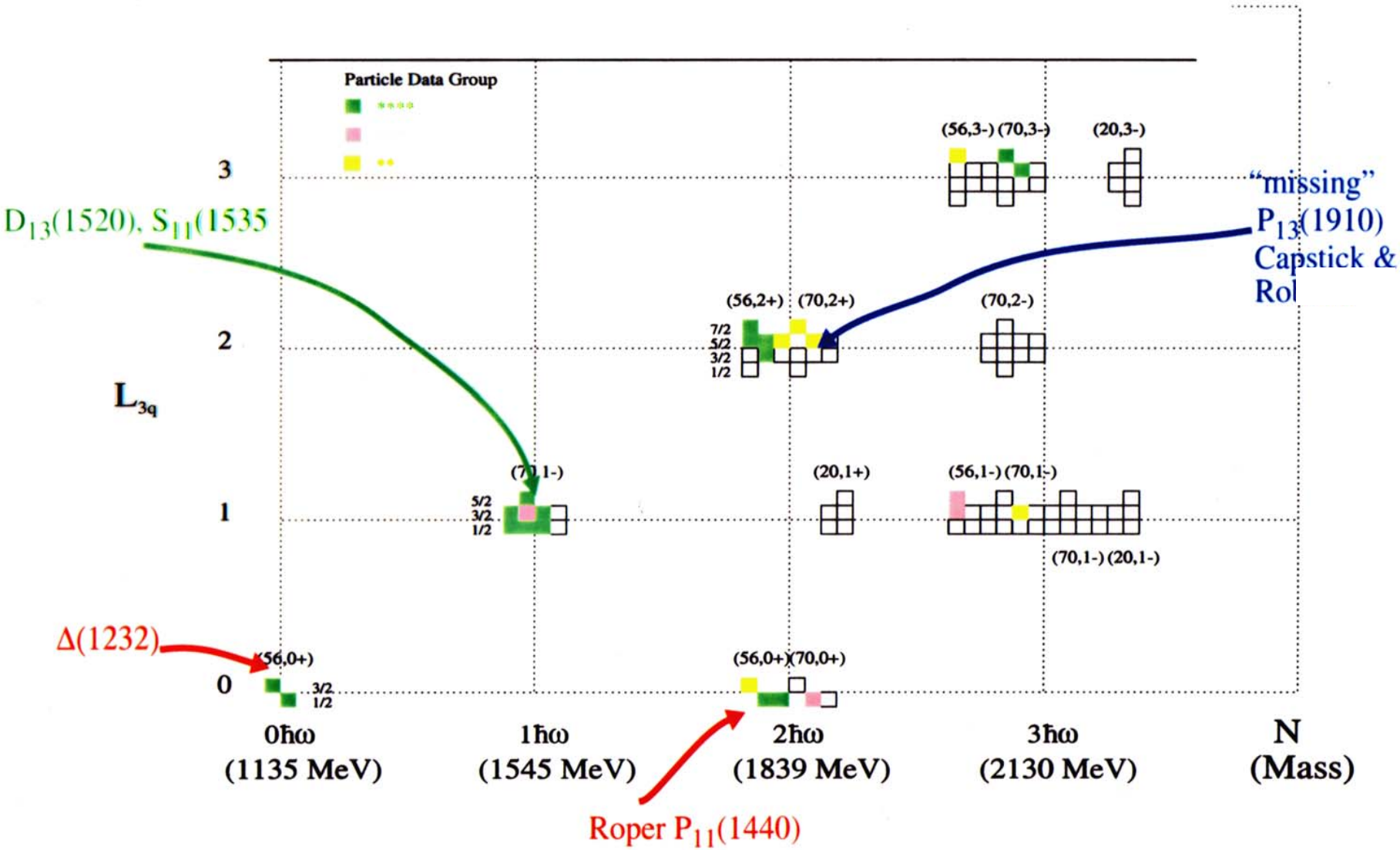
- Light quark baryon spectrum for $N^* \not\to N\pi$

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

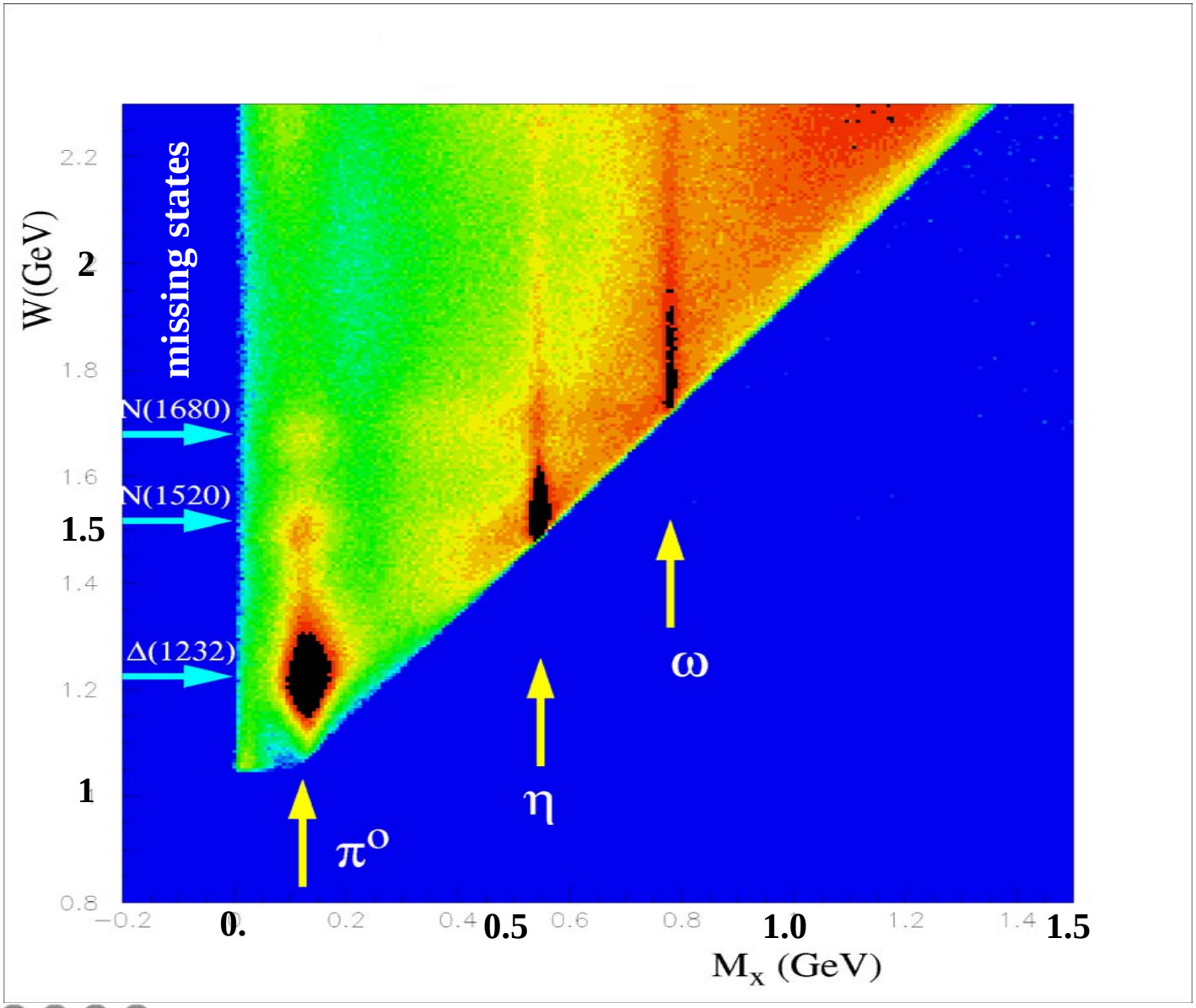
- Meson production mechanism



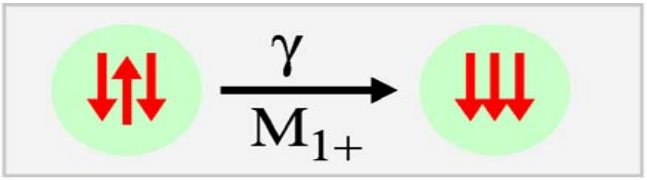
Lowest Supermultiplets in SU(6)O(3) Symmetry Group



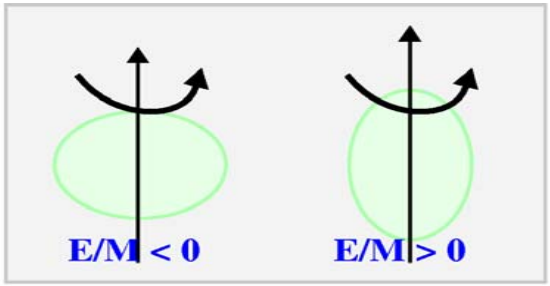
CLAS: ep → epX, E=4GeV



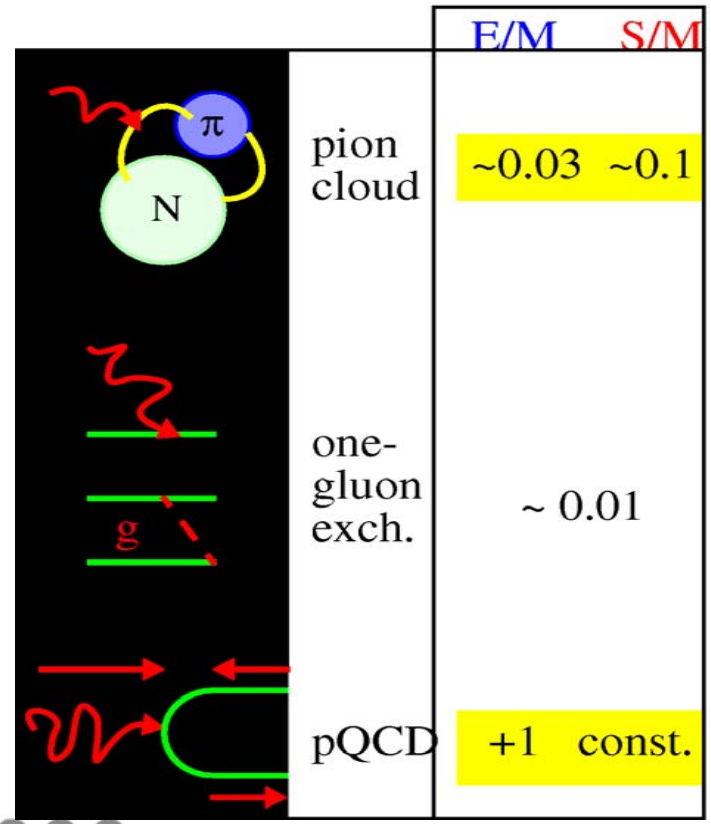
N-Δ(1232) Quadrupole Transition

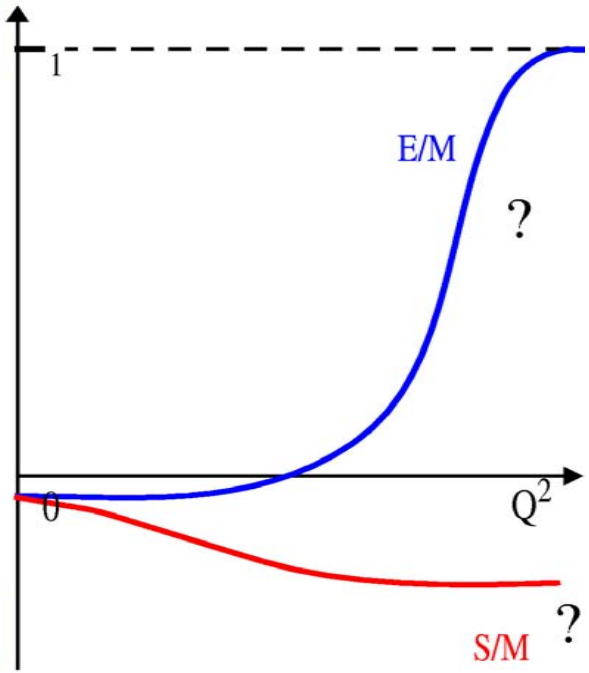


SU(6): $E_{1+}=S_{1+}=0$

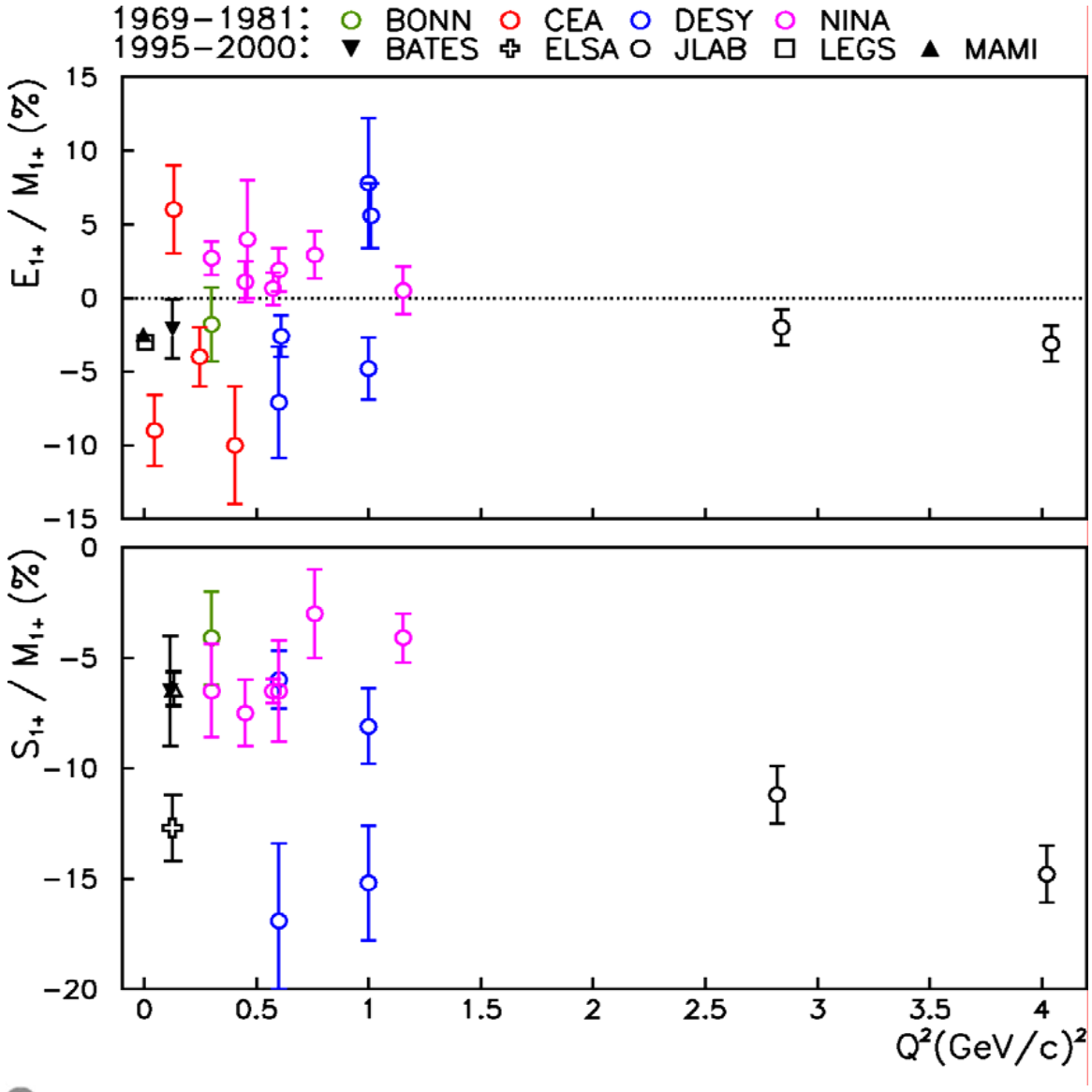


(A. Buchmann, E. Henley, 2000)



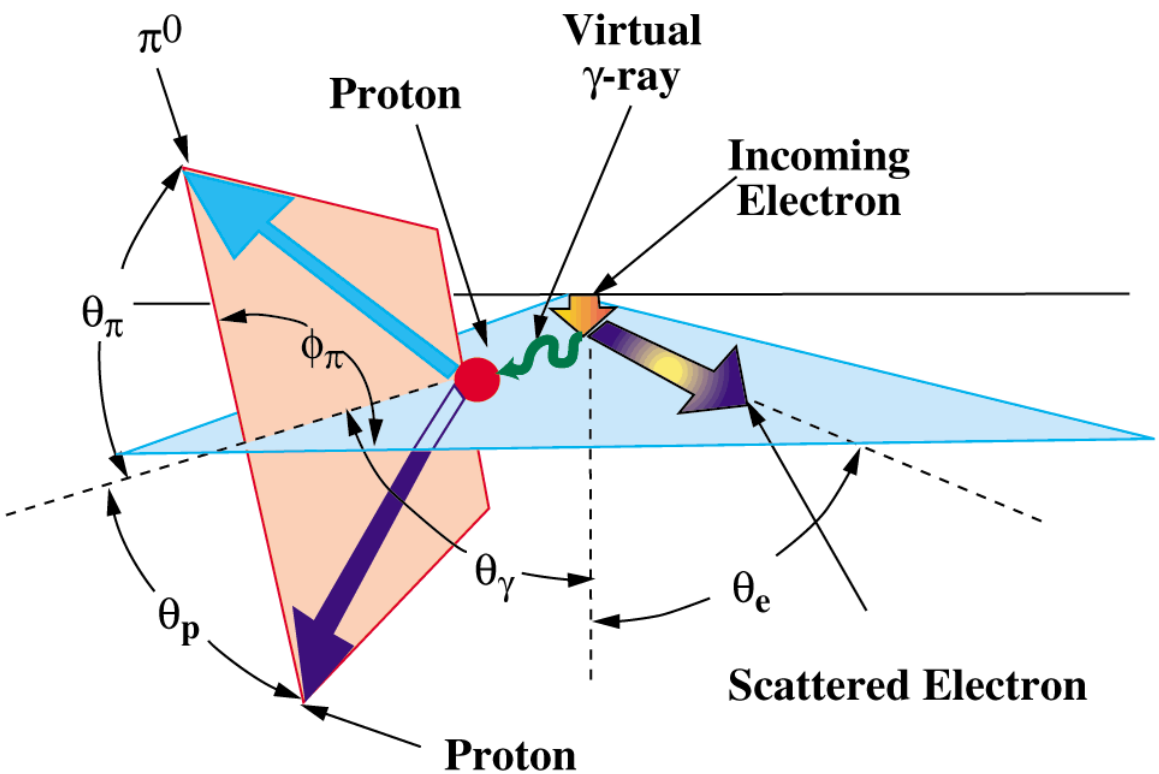


Multipole Ratios R_{EM}, R_{SM} - before 2001



Kinematics for ep → epπ^0

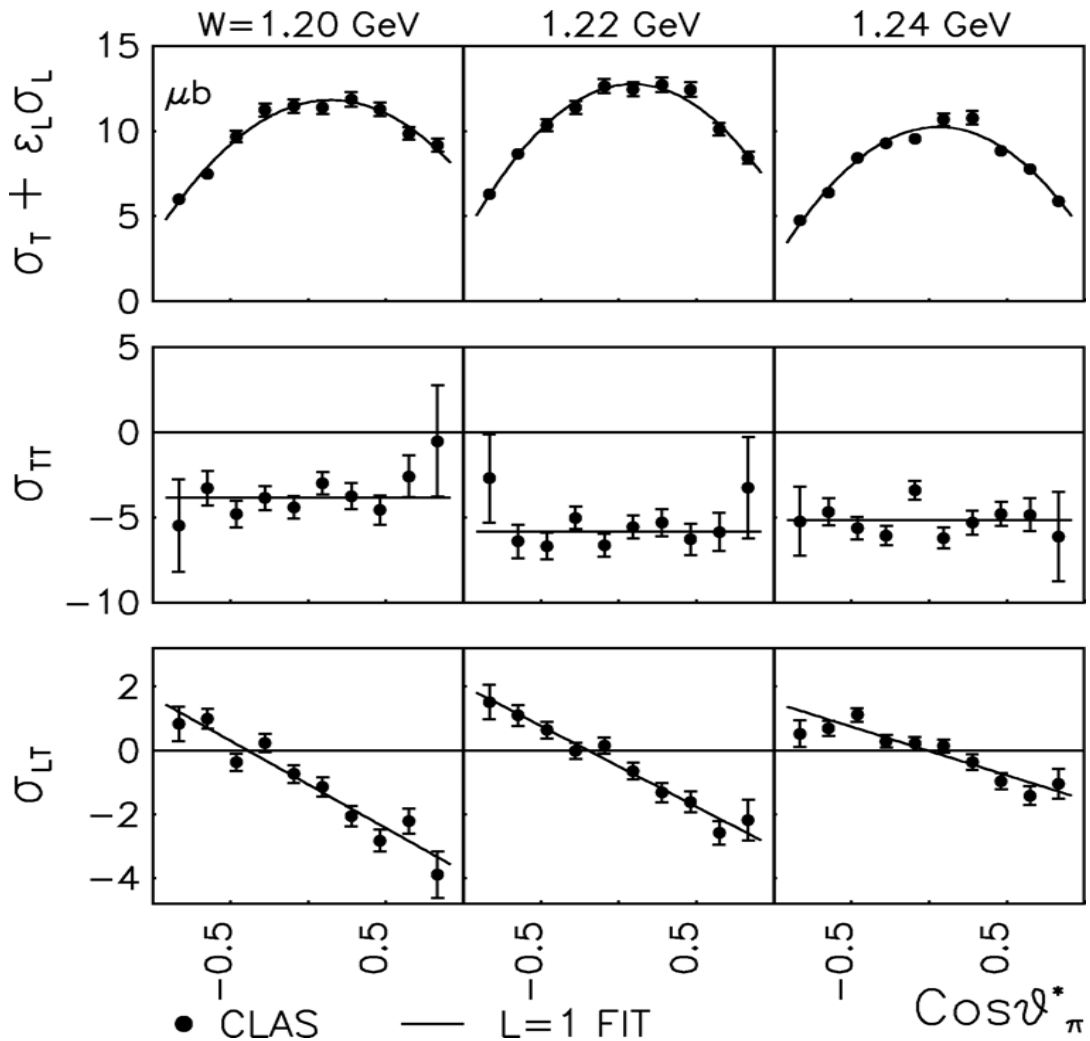
$$\frac{d\sigma}{d\Omega_e dE'_e d\Omega_\pi} = \Gamma_t \left(\sigma_t + \varepsilon\sigma_l + \varepsilon\sigma_{tt} \cos 2\phi_\pi + \sqrt{2\varepsilon(\varepsilon+1)} \cdot \sigma_{tl} \cos \phi_\pi \right)$$



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***

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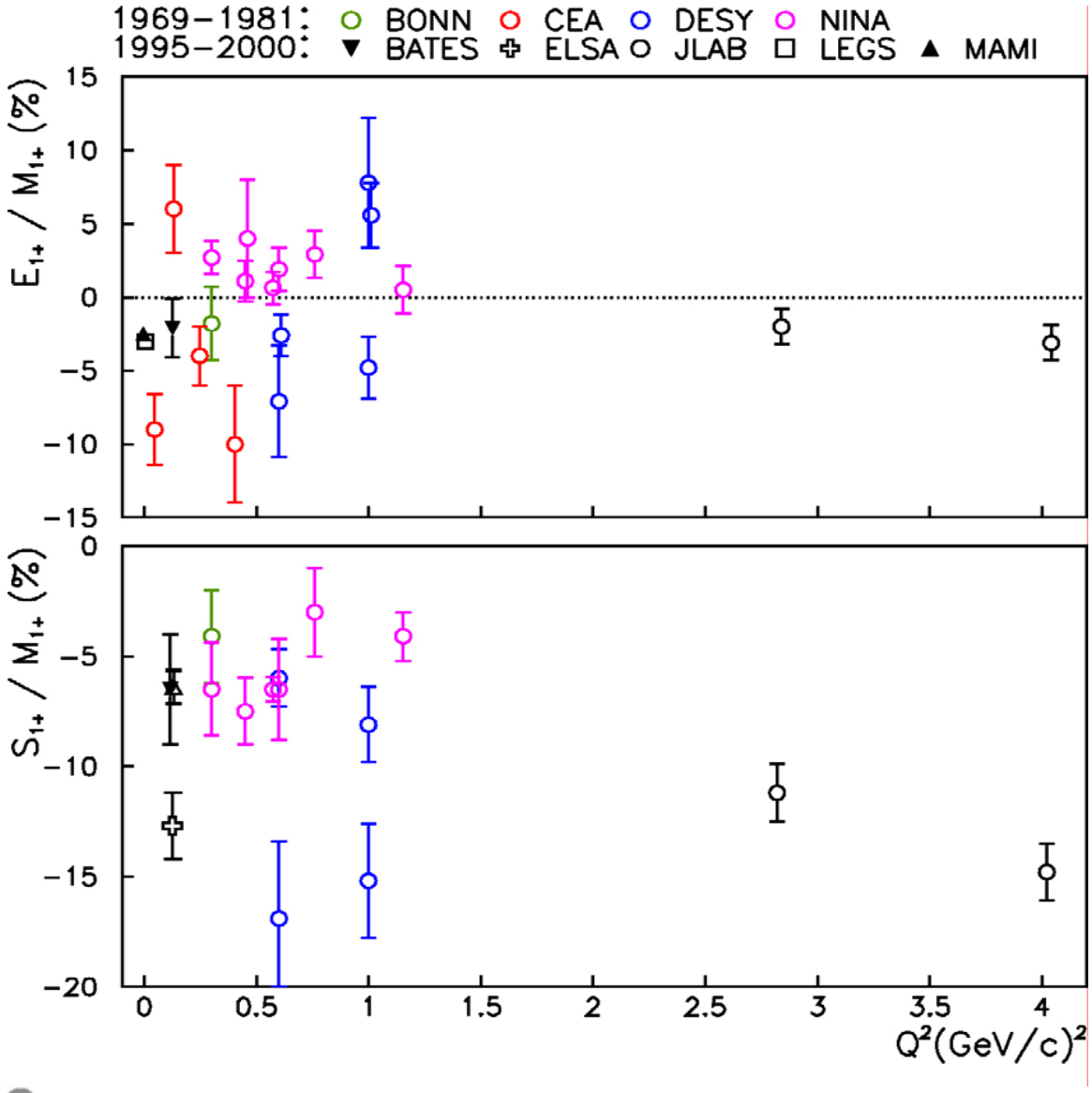
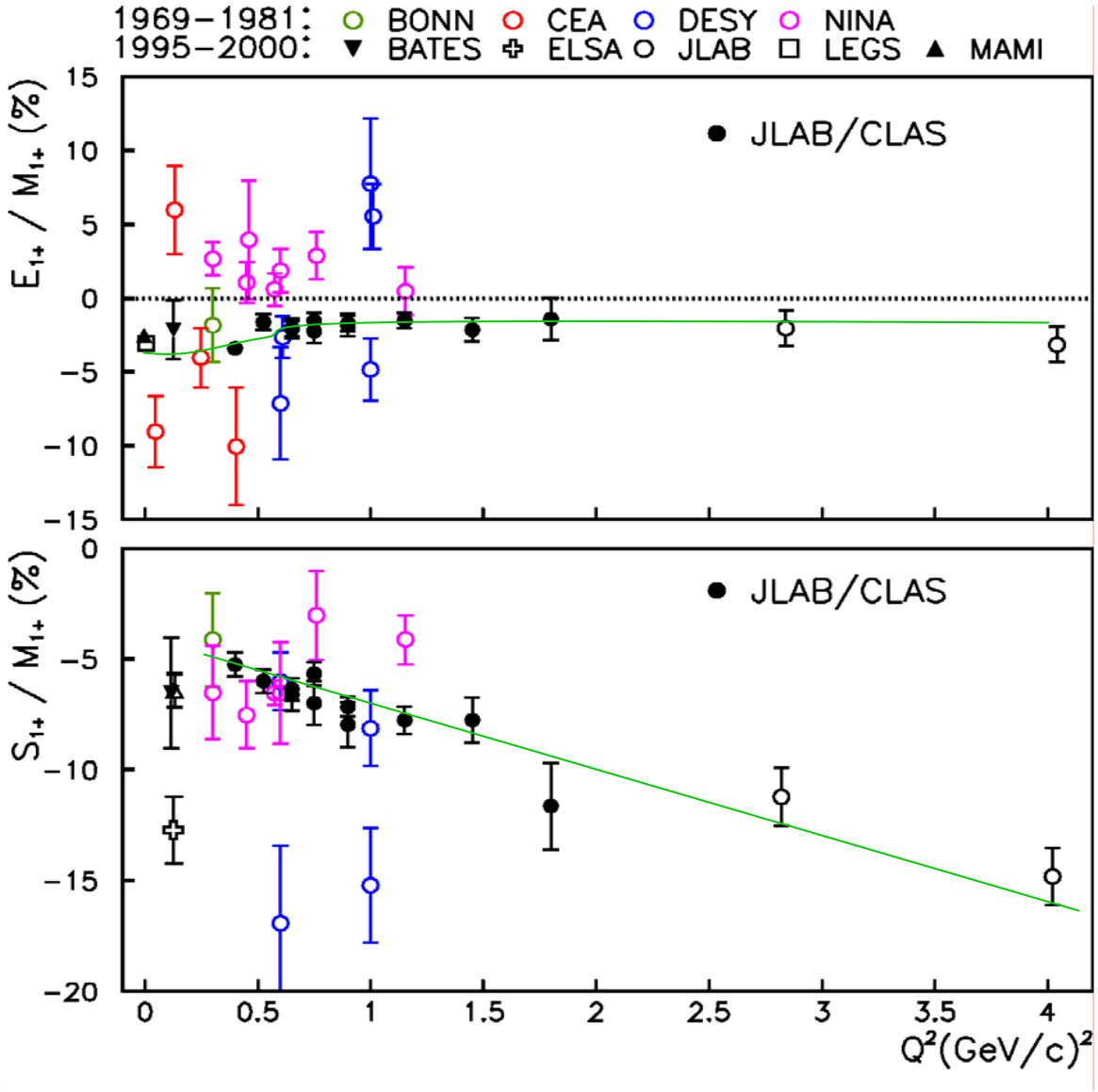
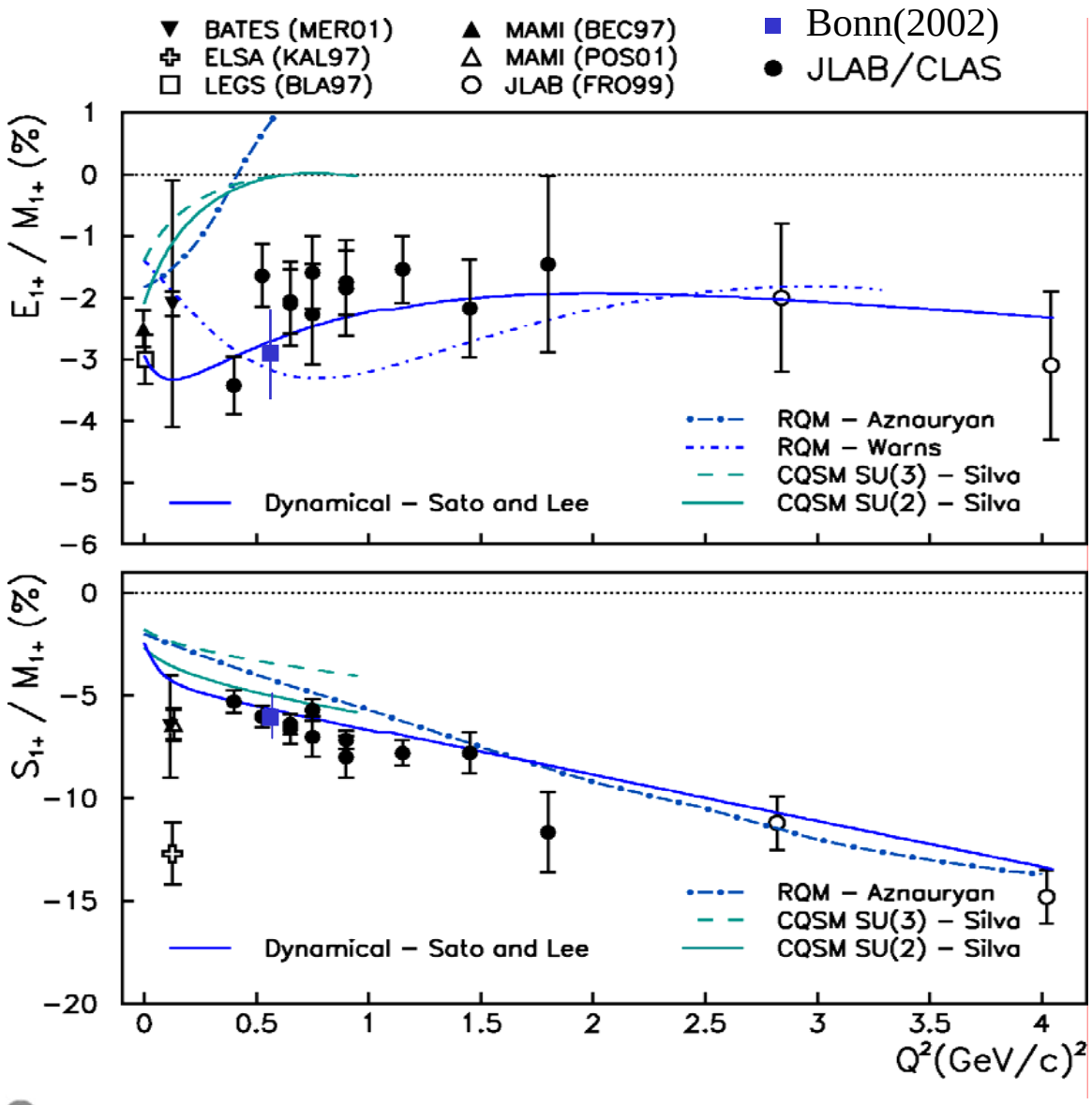


Multipole Ratios R_{EM}, R_{SM} - 2002



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



→ ***Sato***

→ ***Ernst***

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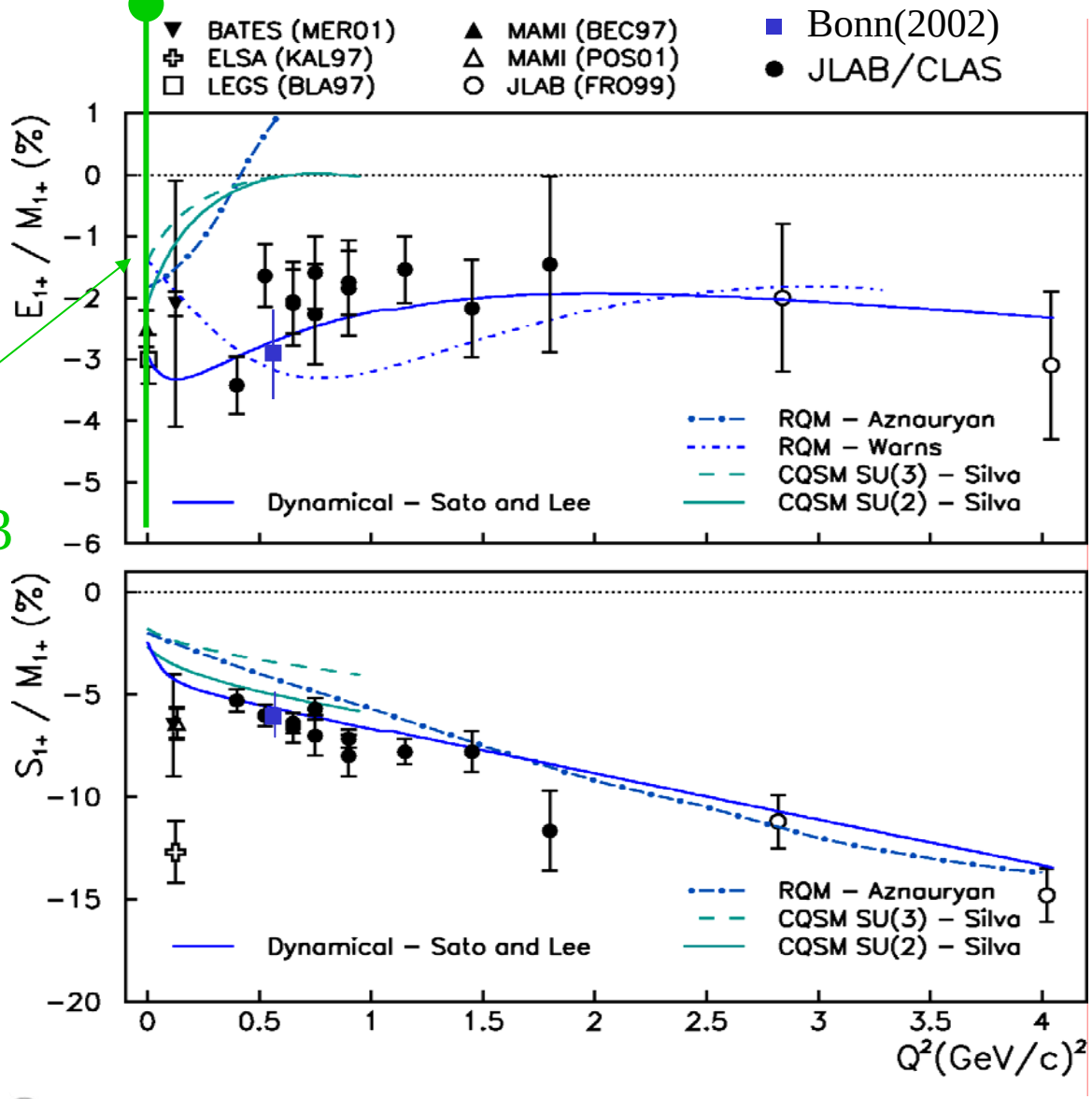

LQCD 1993

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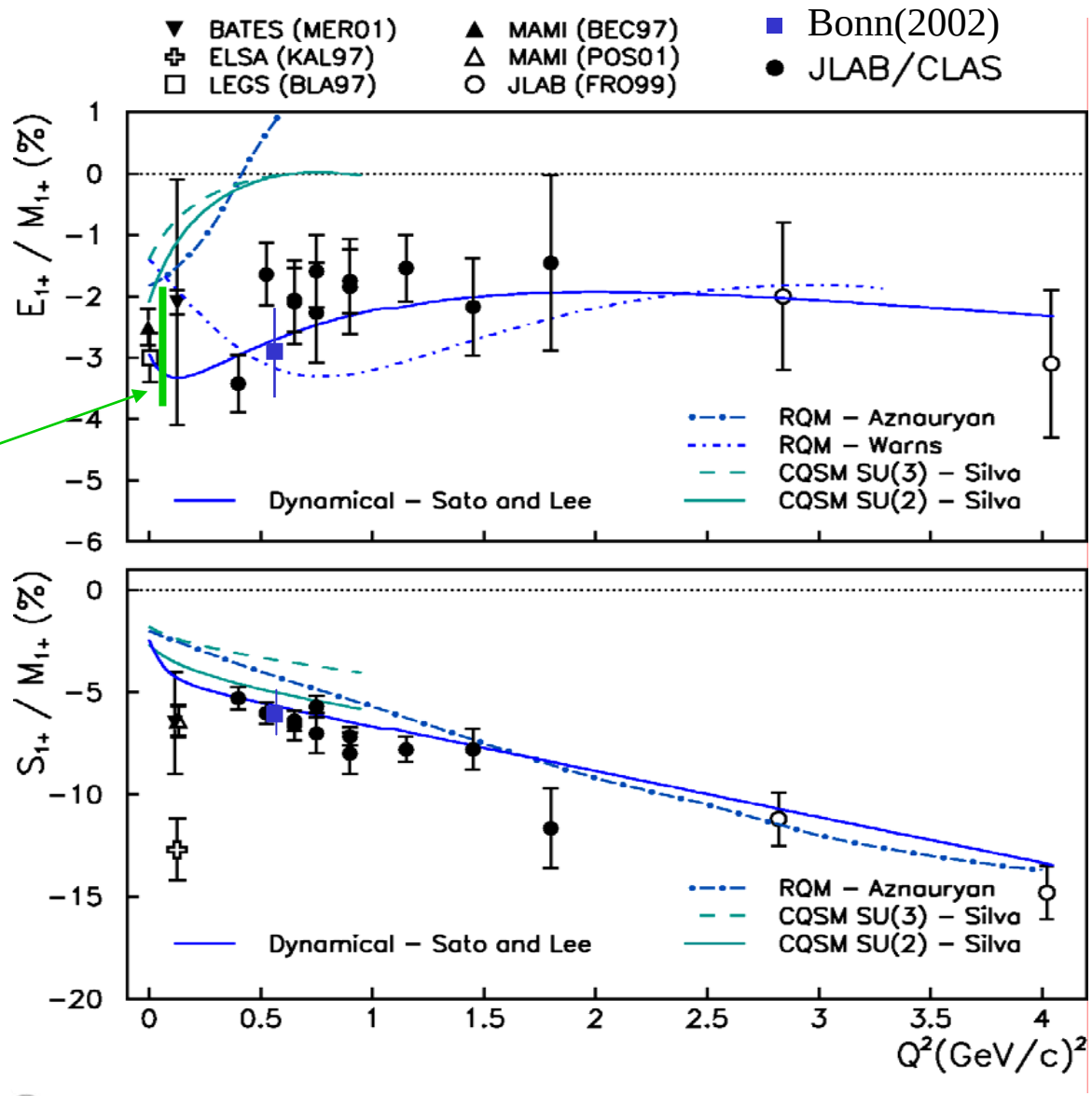


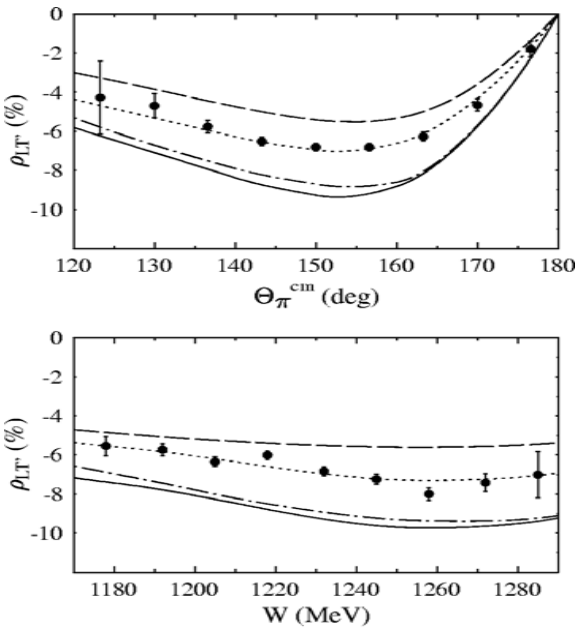
LQCD 2002?

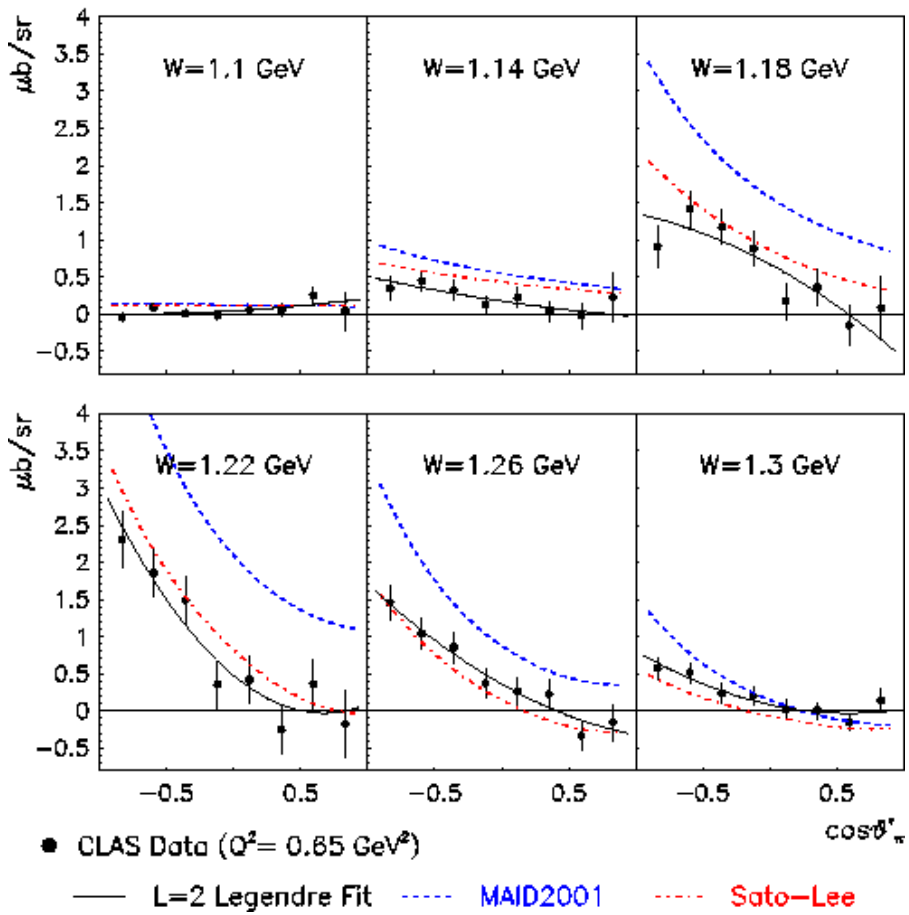
(Moore's law)

Polarized Beam Observable

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

Beam spin asymmetry





Mami/A2

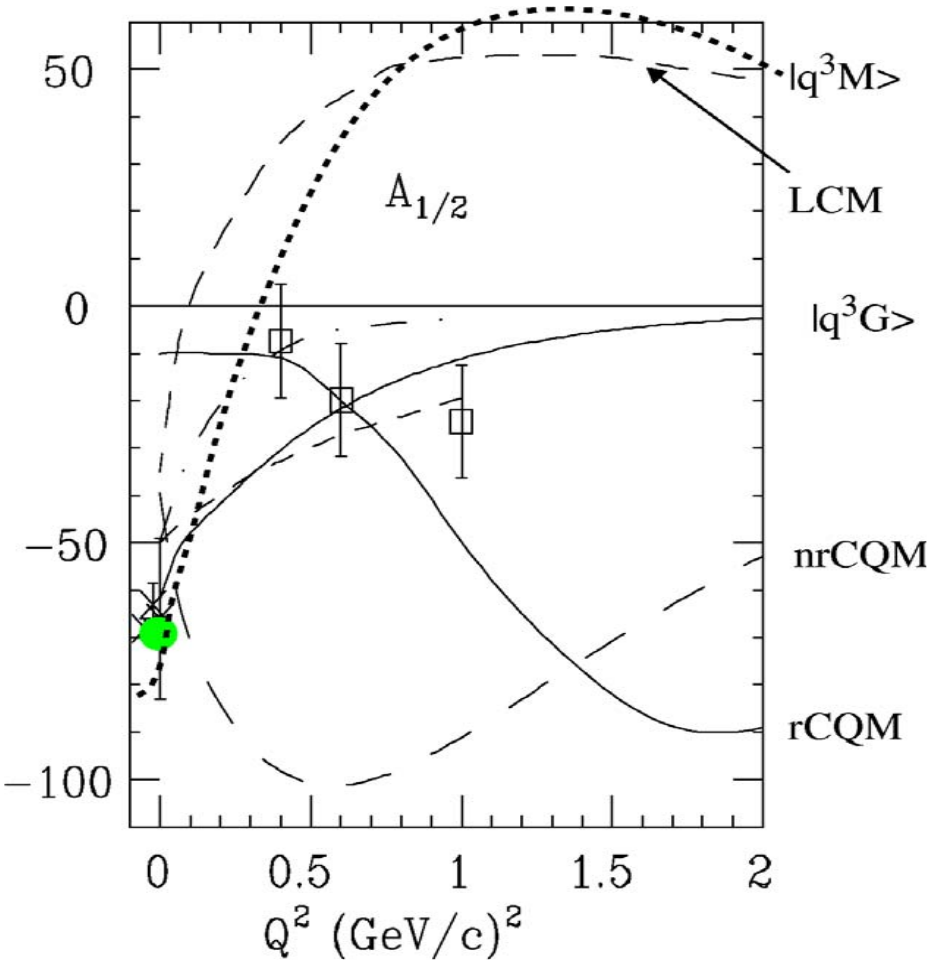
Joo
Botto
Kuhn

The 2nd Resonance Region

The Roper N'(1440)P_{11}

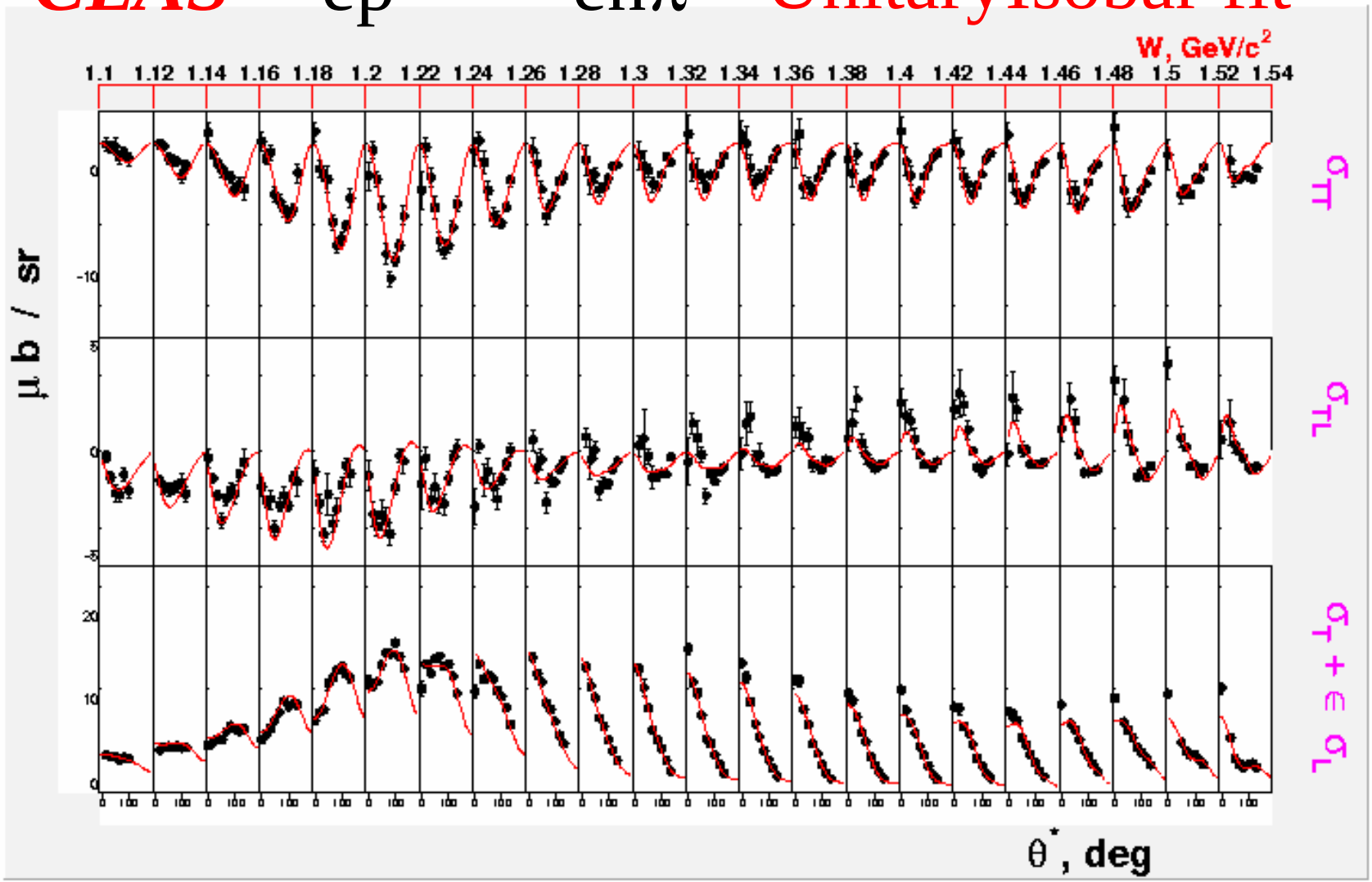
- In CQM assigned as a N=2 radial excitation of the nucleon
- Poor description of properties such as mass, photocouplings, Q^2 evolution

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



The 2nd Resonance Region

CLAS $ep \longrightarrow en\pi^+$ UnitaryIsobar fit



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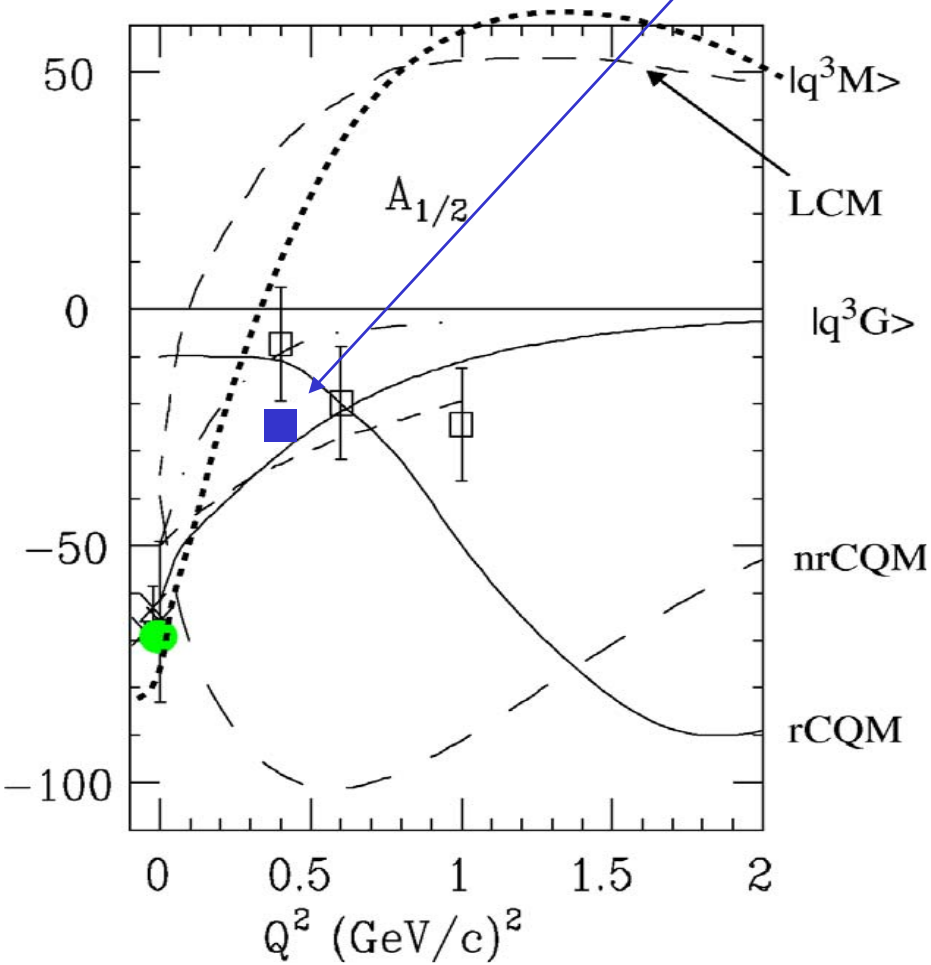
→ ***H. Egiyan***

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 $|q^3\rangle$ state but a $|K\Sigma\rangle$ molecule

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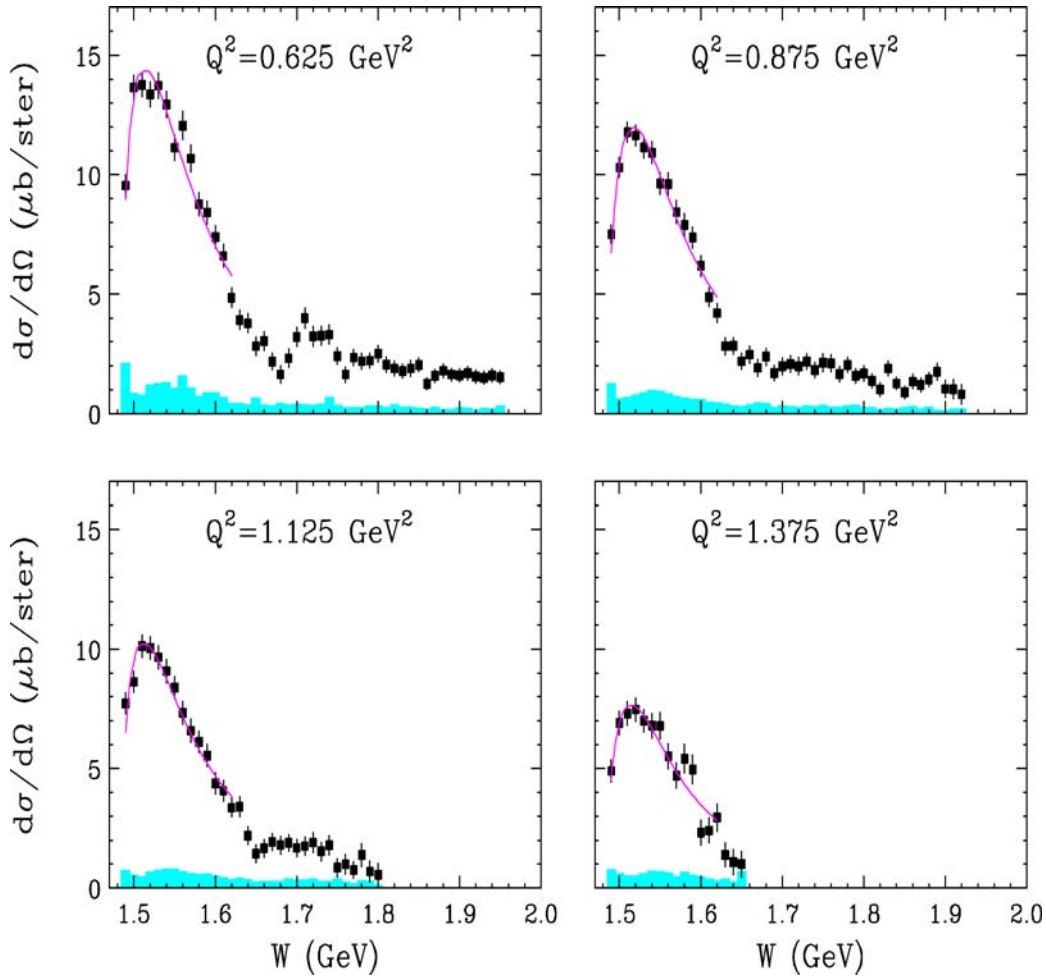
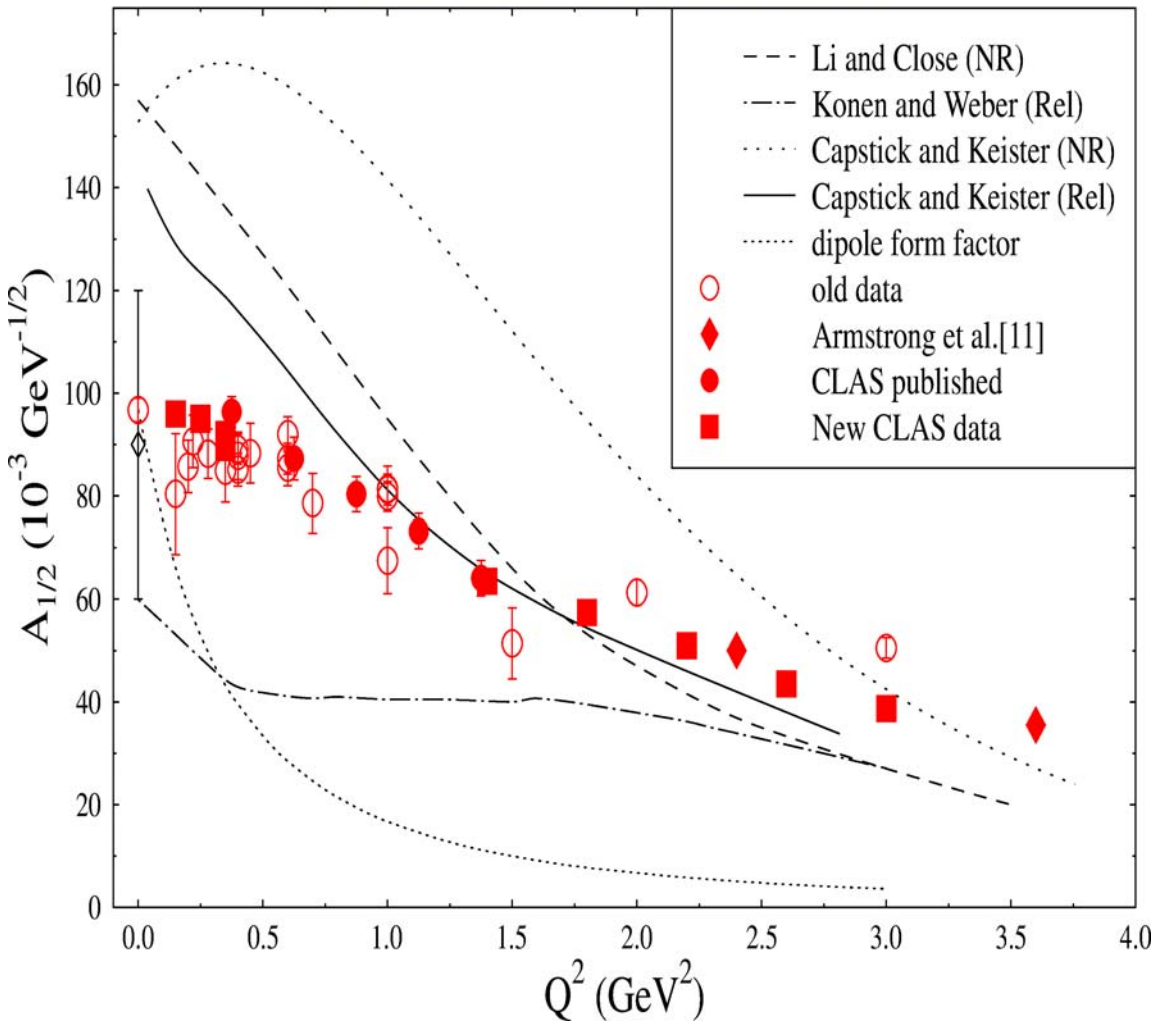


The 2nd Resonance Region

Photocoupling amplitude $A_{1/2}$

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

- Consistent Q^2 evolution from η production



→ ***H. Denizli***

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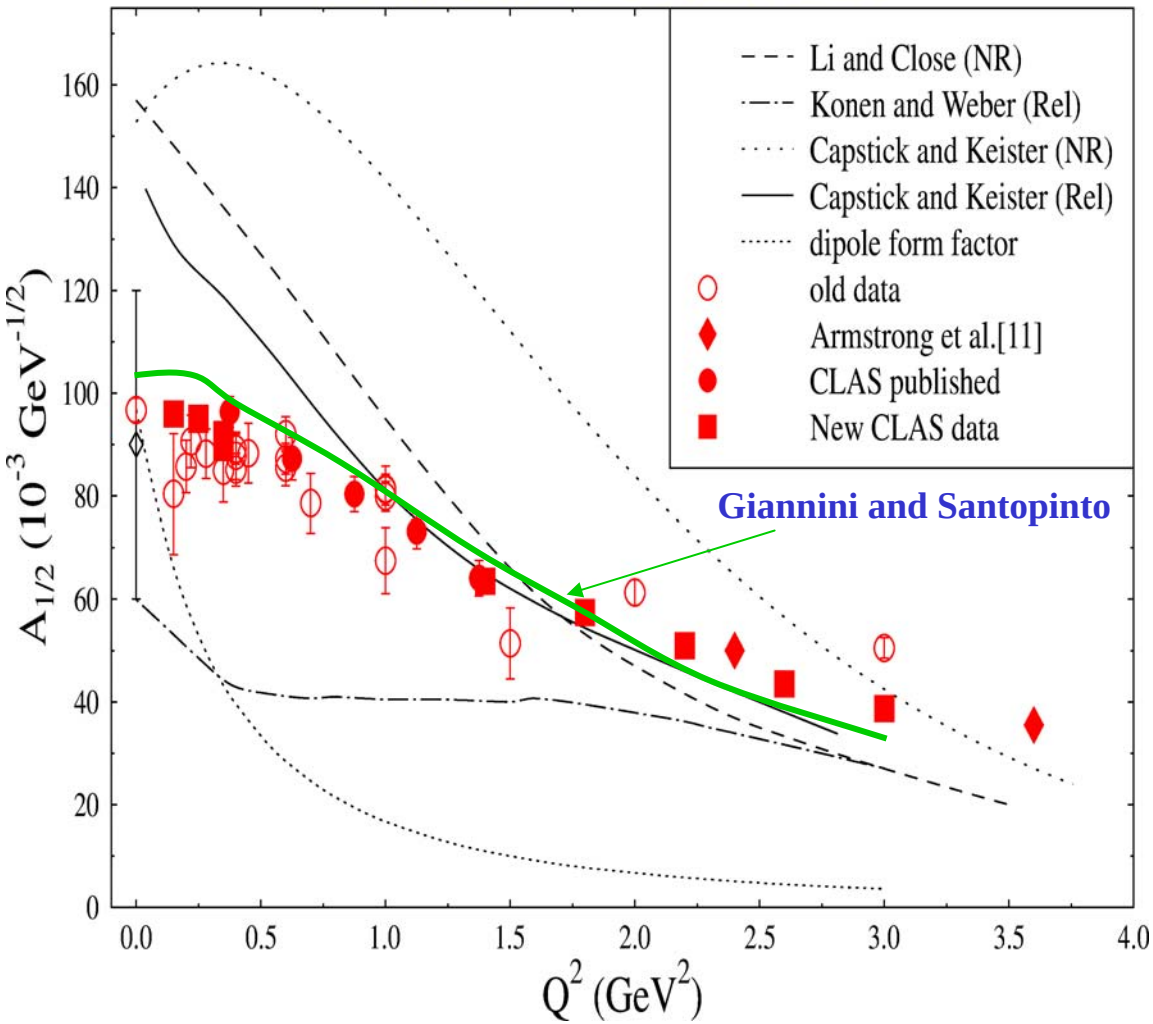

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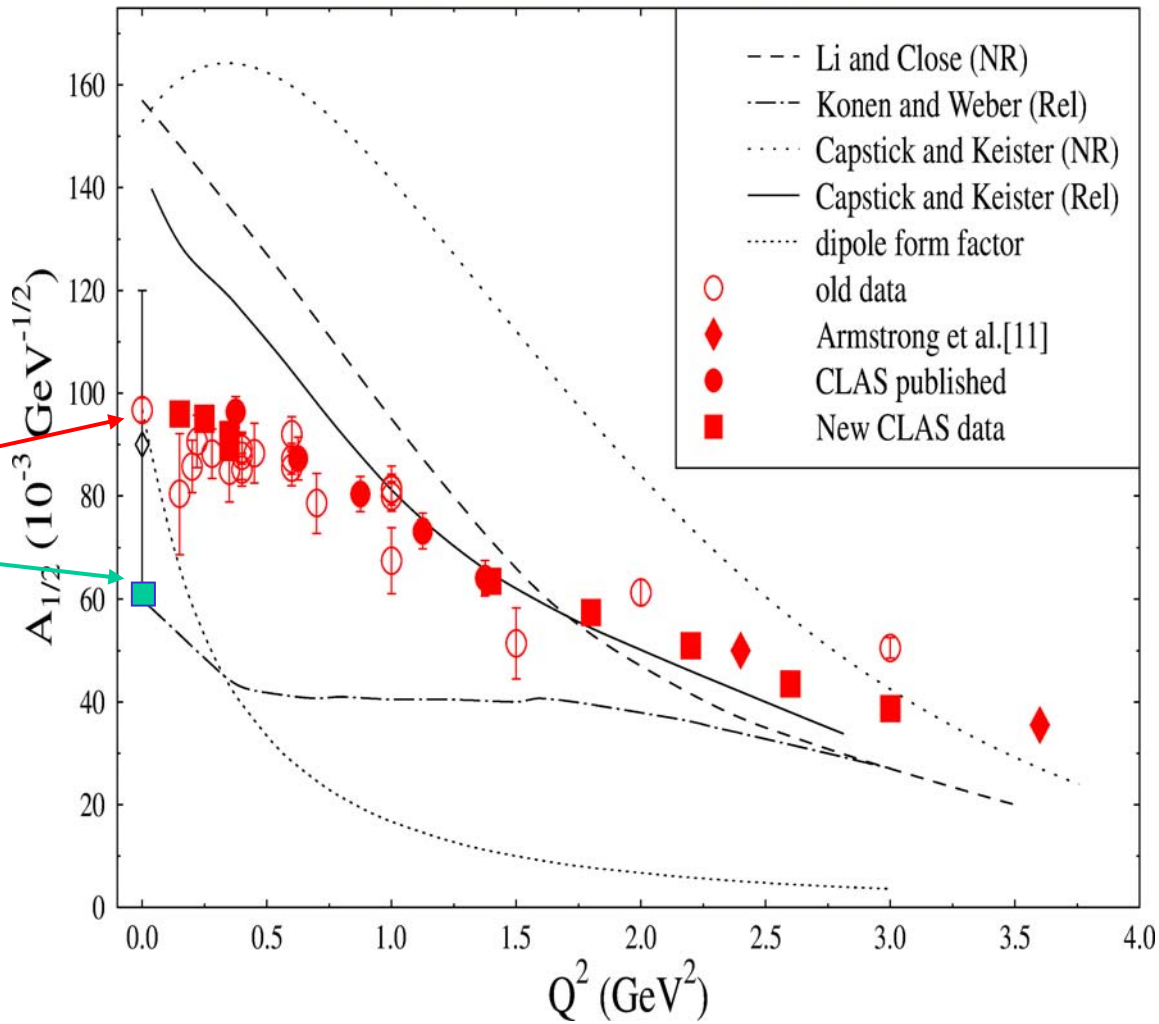

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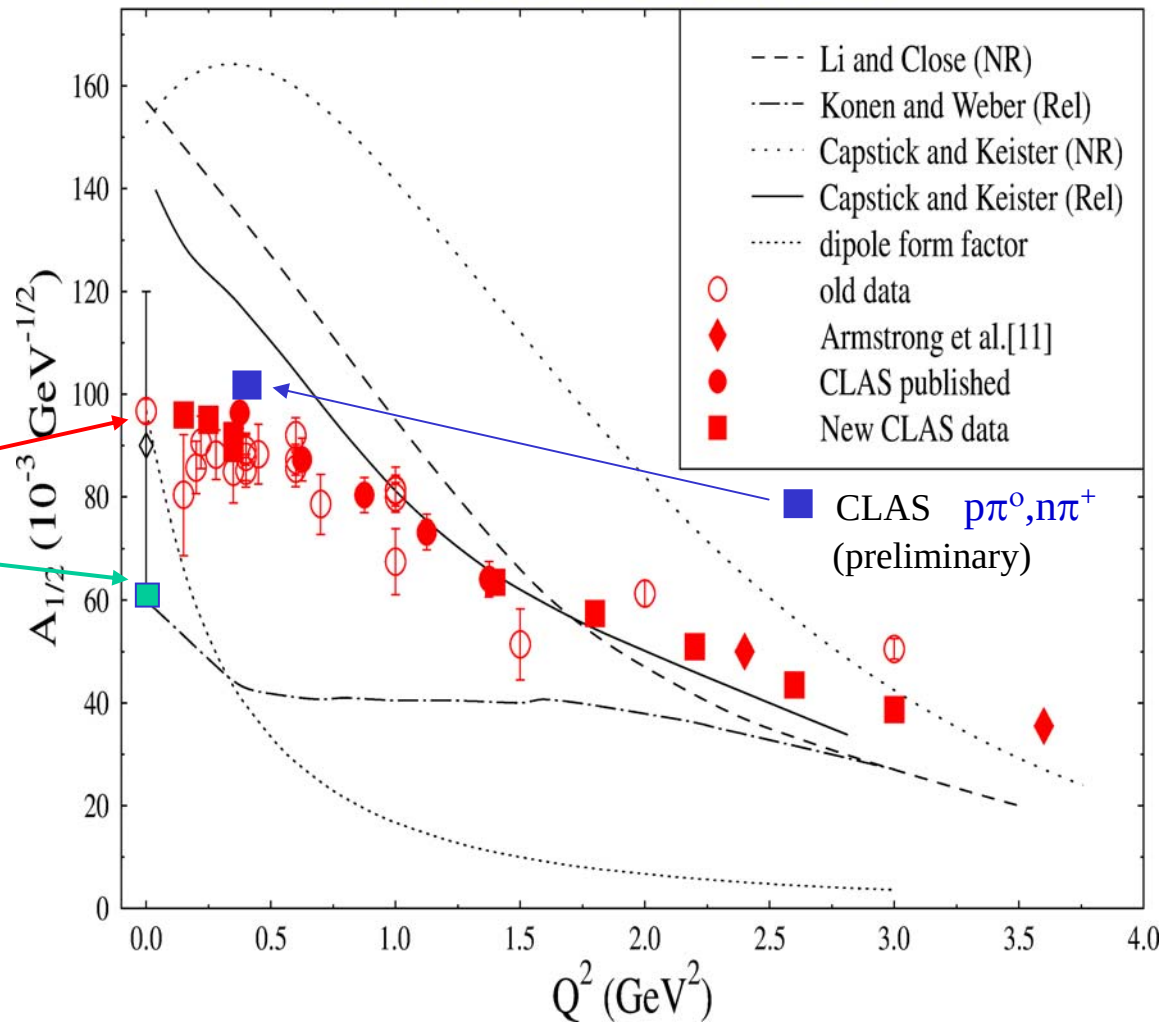
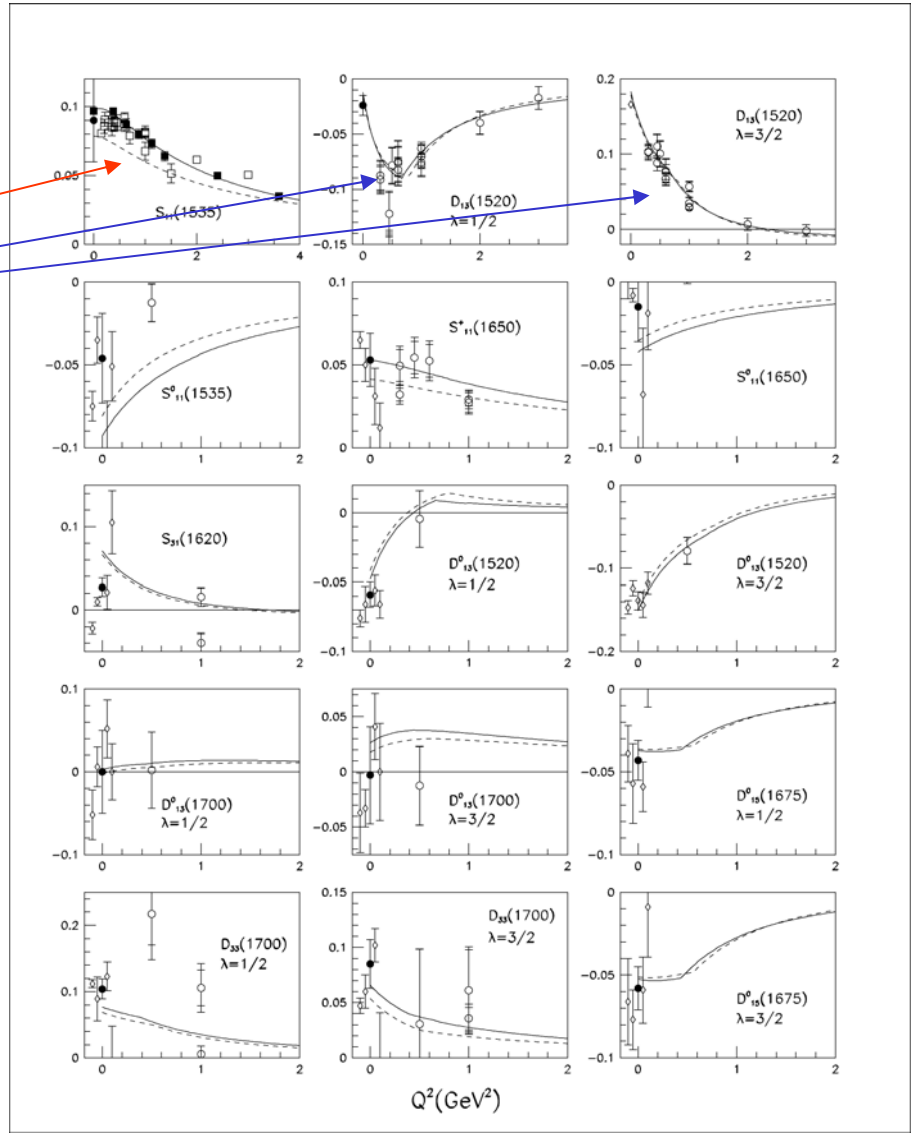
- Discrepancy with Nπ analysis
- ***CLAS*** pη and Nπ data consistent



Single Quark Transition Model

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



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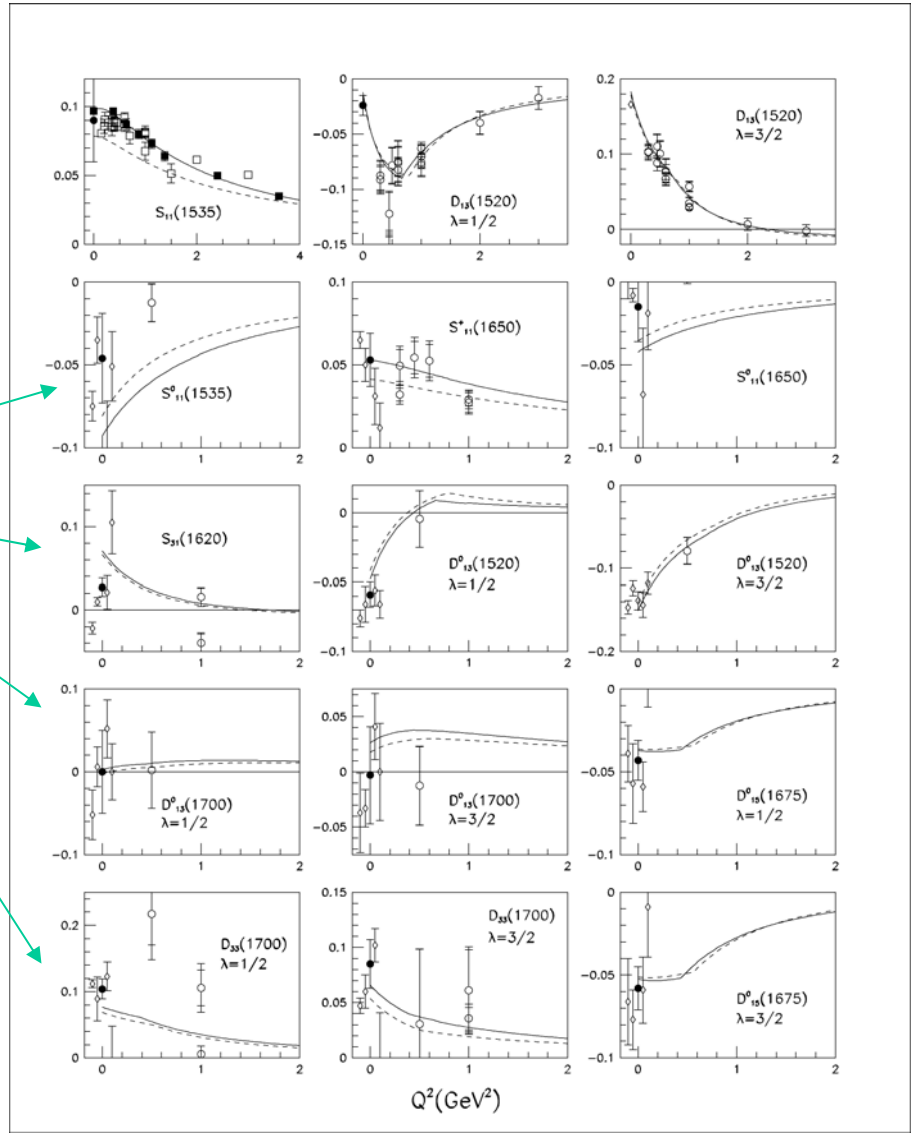
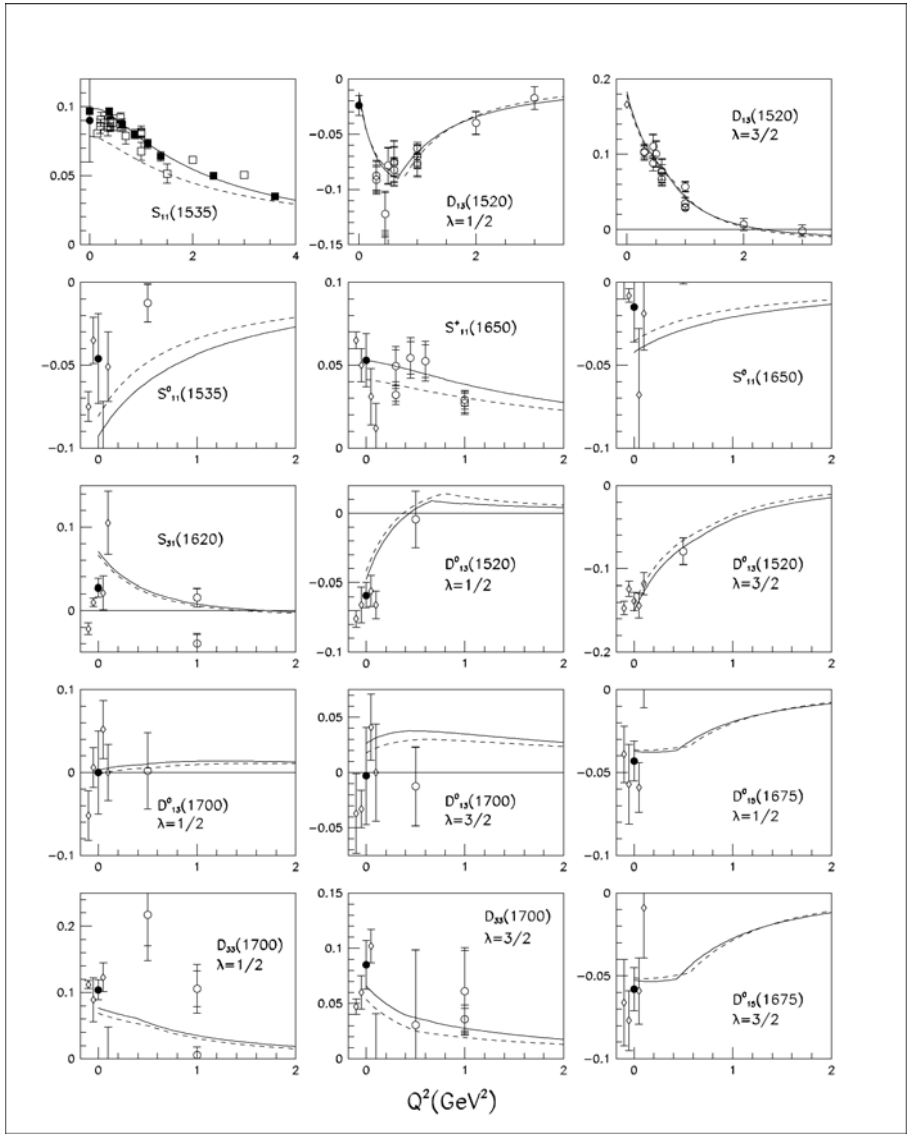
- Predicts all other amplitudes in same supermultiplet



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

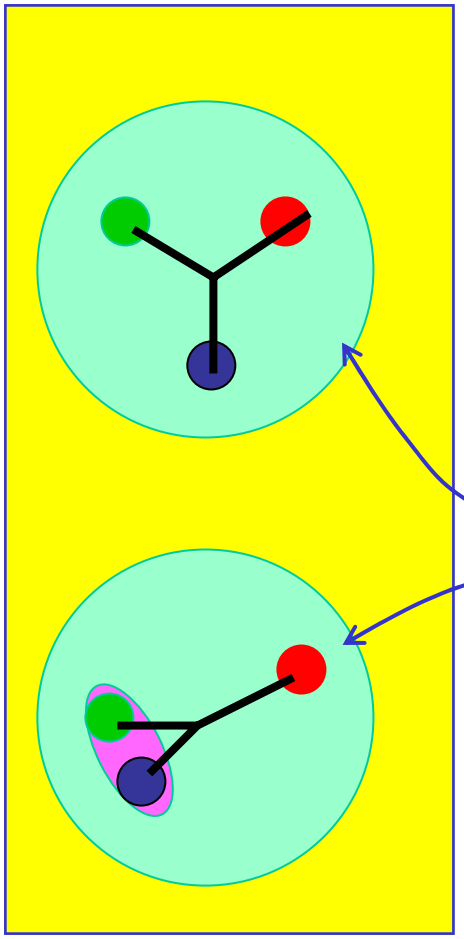


Higher mass and "missing states"

- Higher mass states tend to couple strongly to $N\pi\pi$

State	πN	ηN	πN wave	$\pi\pi N$
$N_{1/2-}(1535)$	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

$|q^3\rangle$ => predicted to couple to
$N\pi\pi$ ($\Delta\pi$, $N\rho$), $N\omega$, KY

which model is closer to reality?

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

→ ***Klempt, Vijande***

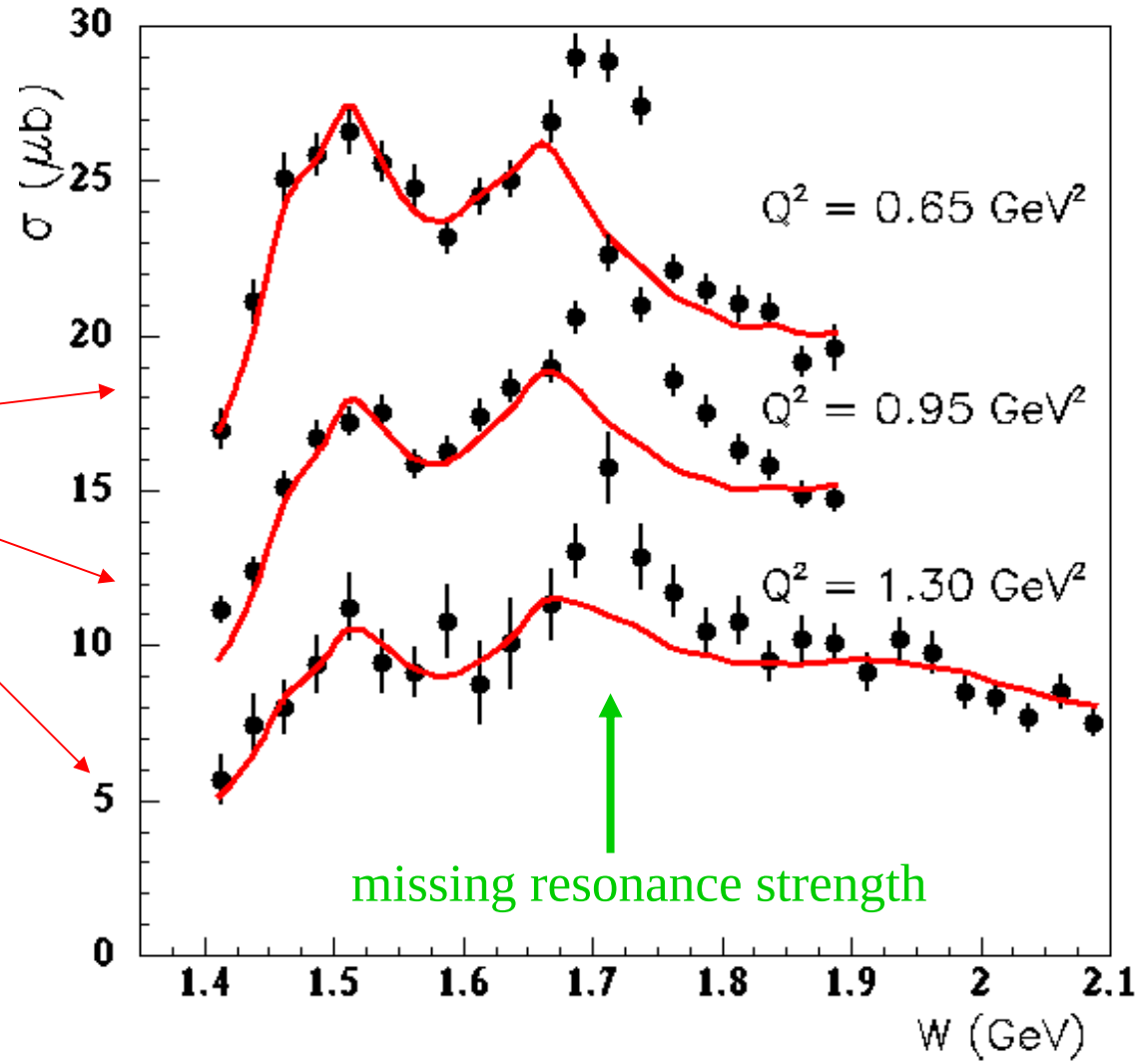
Resonances in $\gamma^* p \rightarrow p\pi^+\pi^-$

CLAS

Genova-Moscow
Isobar model fit

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

Total cross section

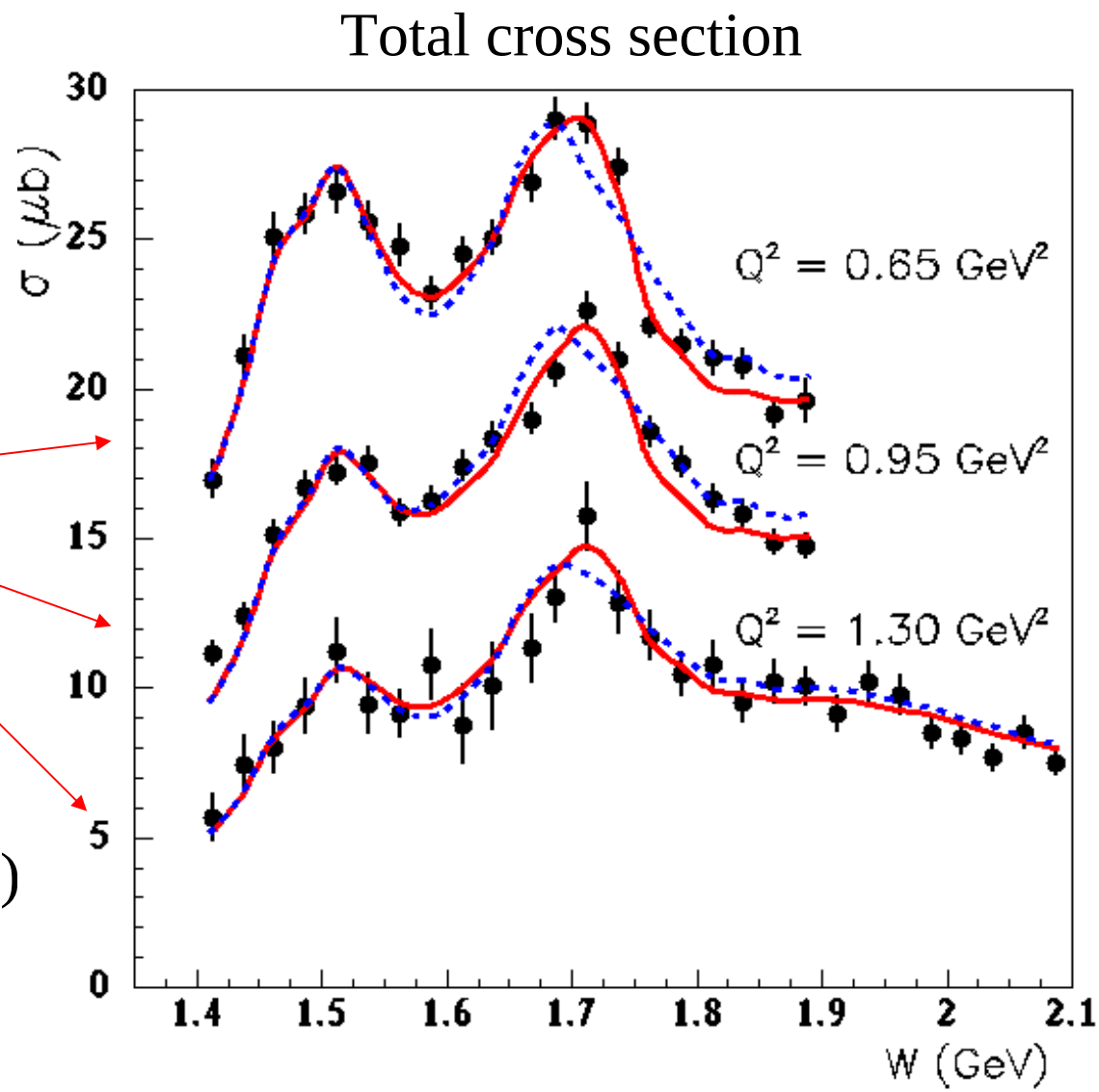


Isobar fit to $D_{13}(1700)$ and new P_{13}

CLAS

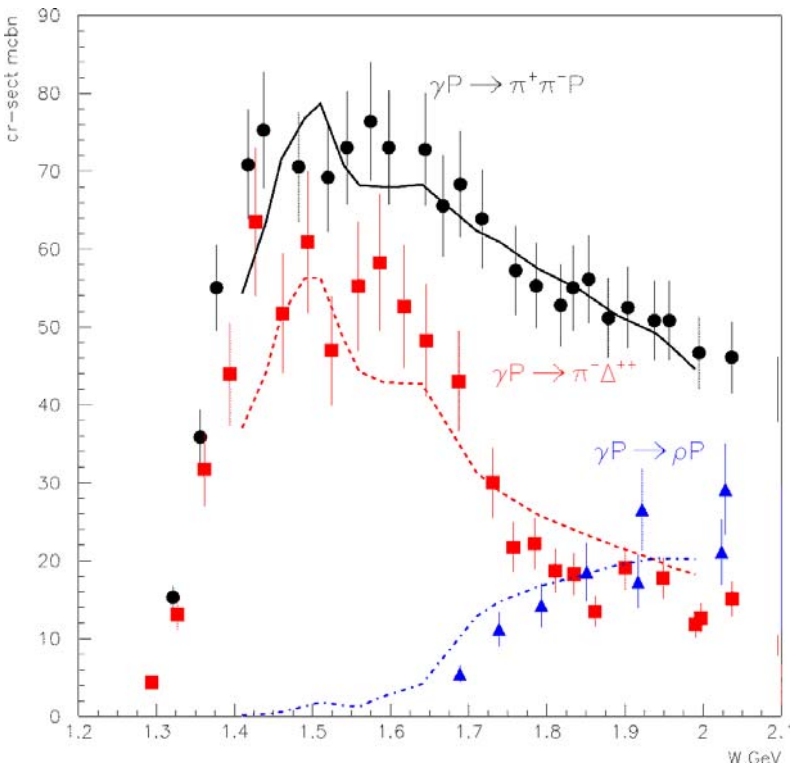
Genova-Moscow
Isobar model fit

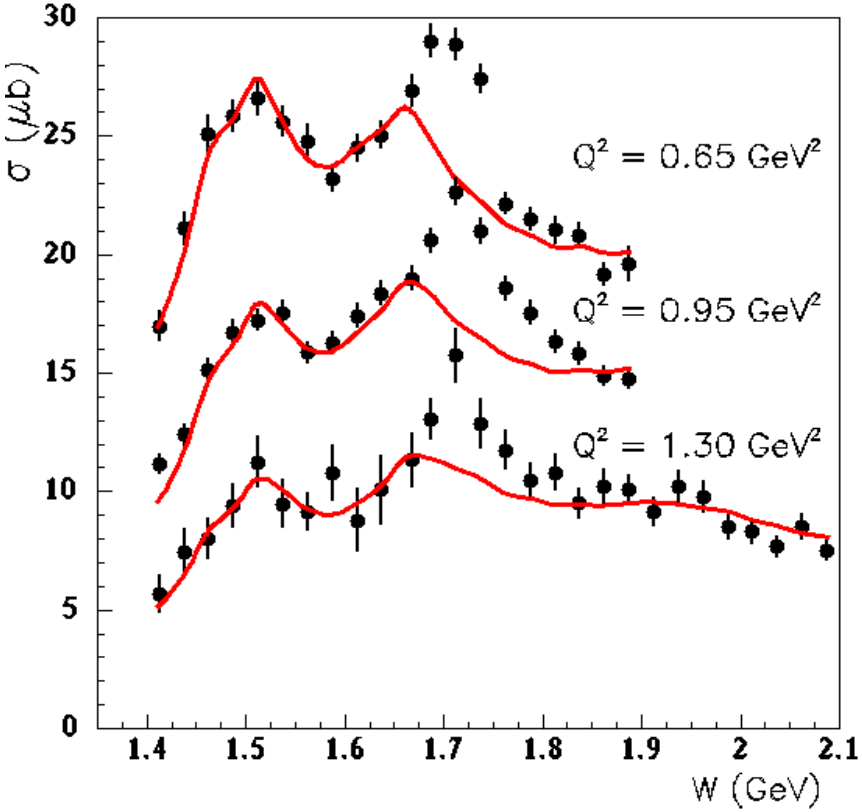
$\Gamma_{N\pi\pi}$ PDG
$\Gamma_{N\gamma}$ AO/SQTM



P_{13}

$D_{13}(1700)$

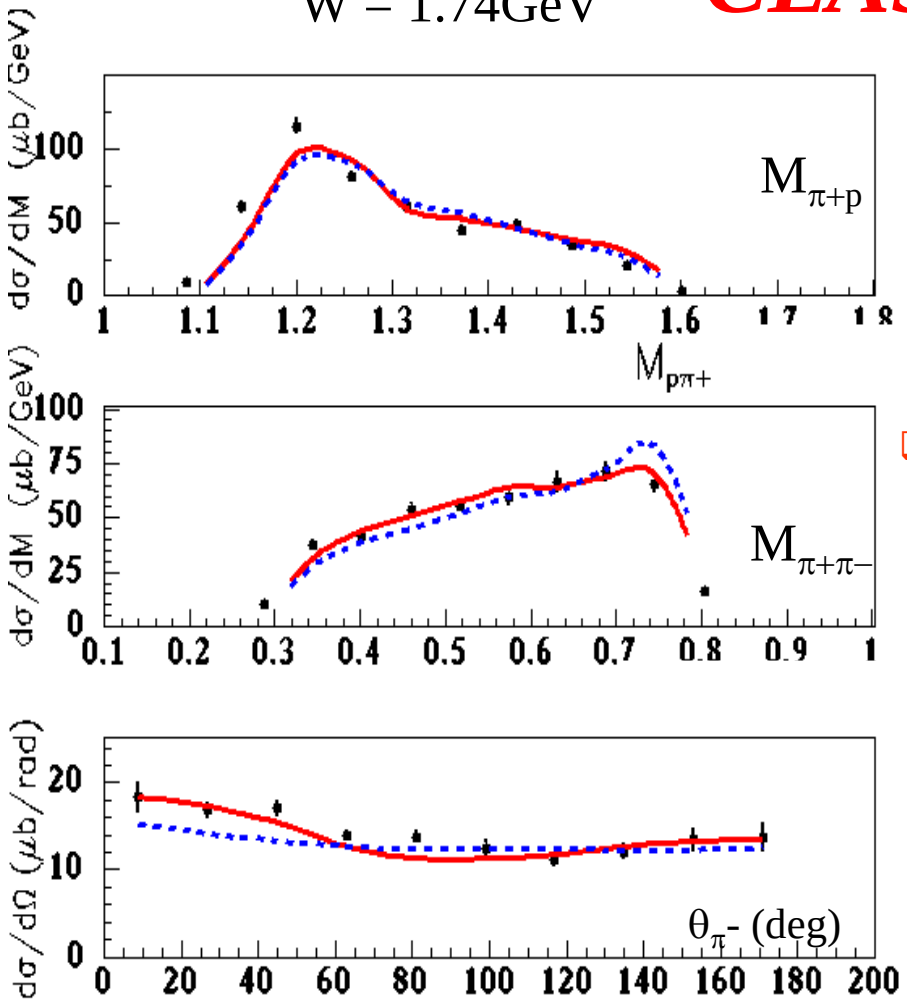

cr-sect mcbn
$\gamma P \rightarrow \pi^+\pi^- P$
$\gamma P \rightarrow \pi^- \Delta^{++}$
$\gamma P \rightarrow \rho P$
W GeV


σ (μb)
Q^2 = 0.65 GeV^2
Q^2 = 0.95 GeV^2
Q^2 = 1.30 GeV^2
W (GeV)

Isobar fit - hadronic decays

W = 1.74GeV

CLAS



P_{13}

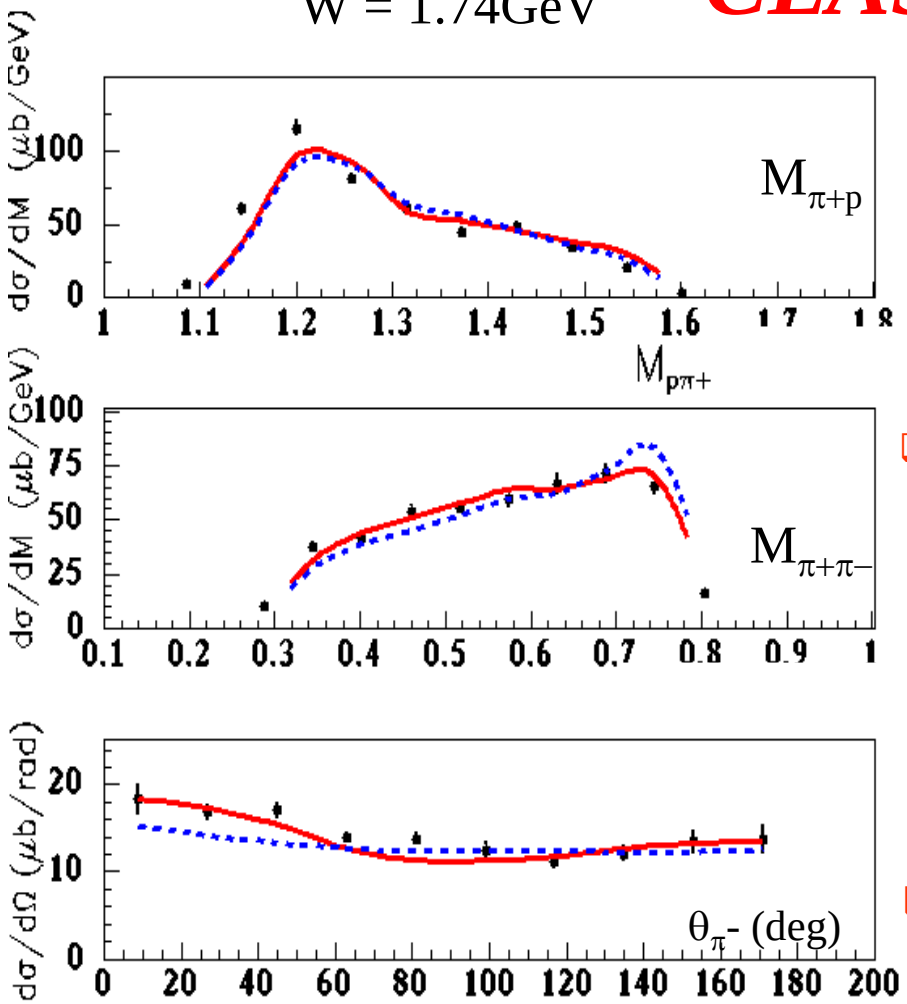
$D_{13}(1700)$

- Data described best by new P_{13}

M = 1.72 +/- 0.02 GeV
Γ_T = 88 +/- 17 MeV
$\Delta\pi$: 0.41 +/- 0.13
$N\rho$: 0.17 +/- 0.10

Isobar fit - A new state?

W = 1.74GeV **CLAS**



P_{13}

$D_{13}(1700)$

- 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}

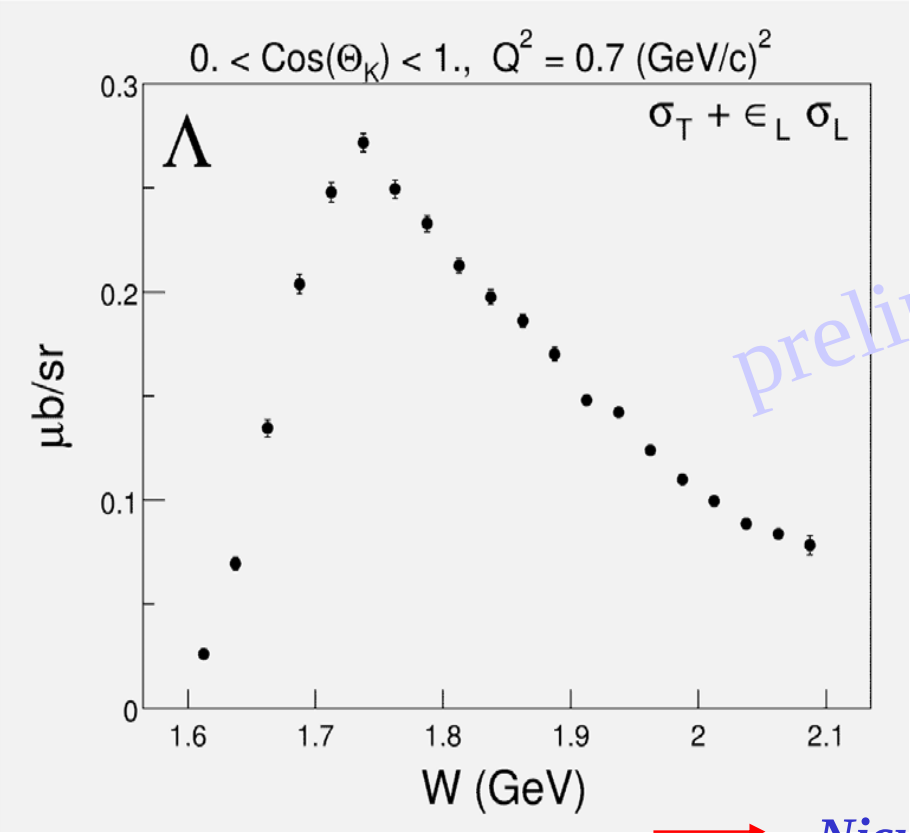
- consistent with "missing" P_{13} state, but mass low

→ ***F. Klein***

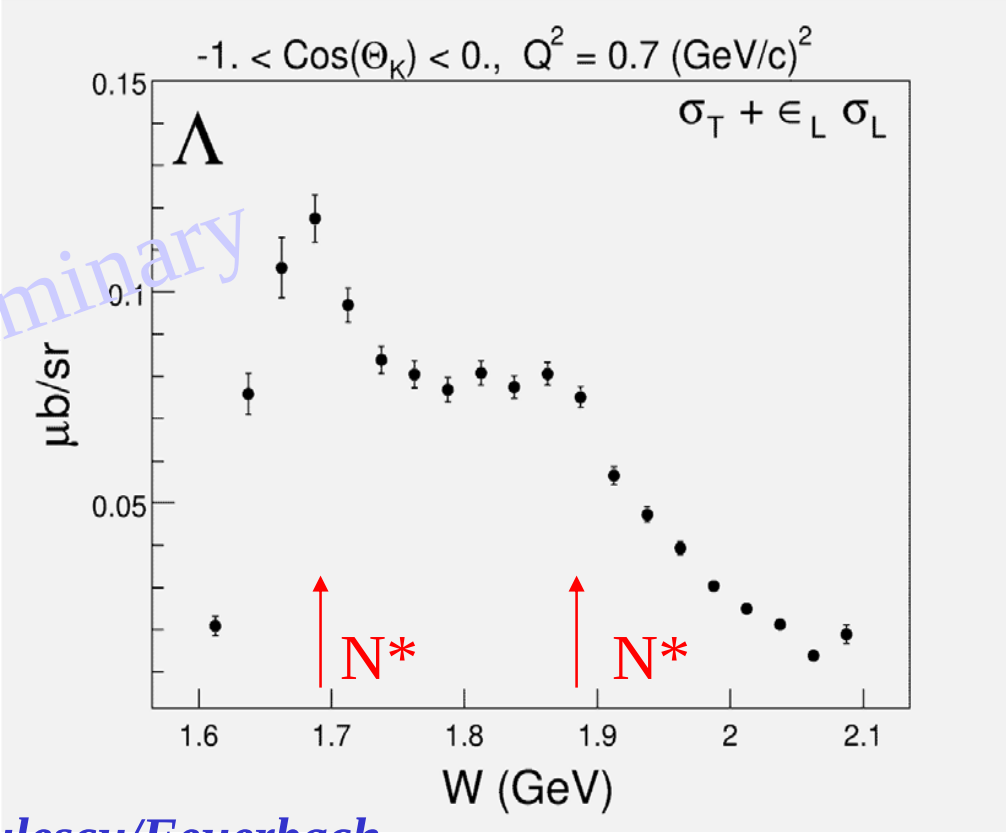
Search for resonances in hyperon production

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

forward hemisphere



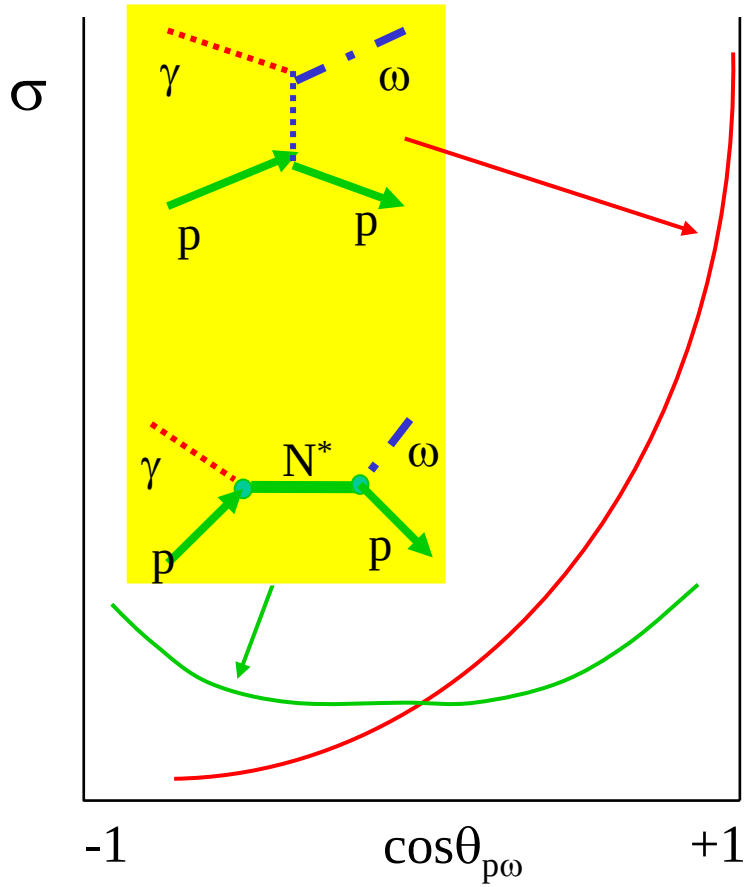
backward hemishere



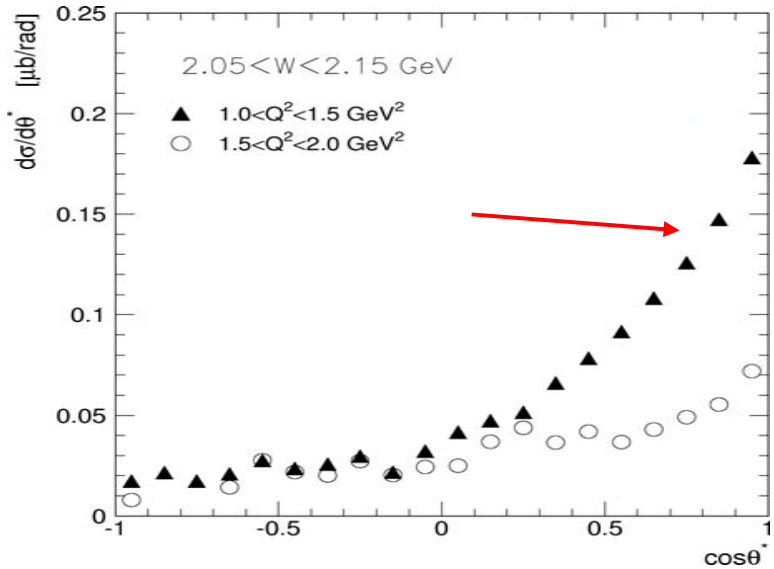
preliminary

→ ***Niculescu/Feuerbach***

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

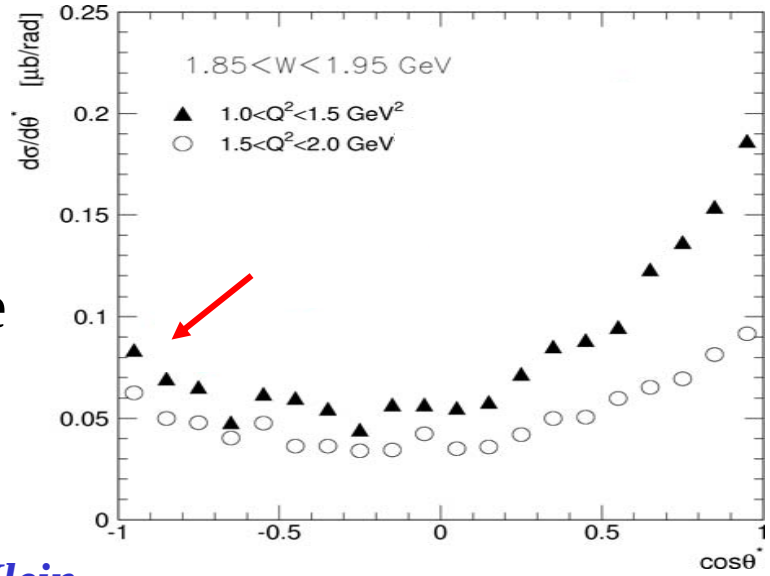


above resonance region



CLAS

in resonance region



→ ***F. Klein***

Resonances in Virtual Compton Scattering

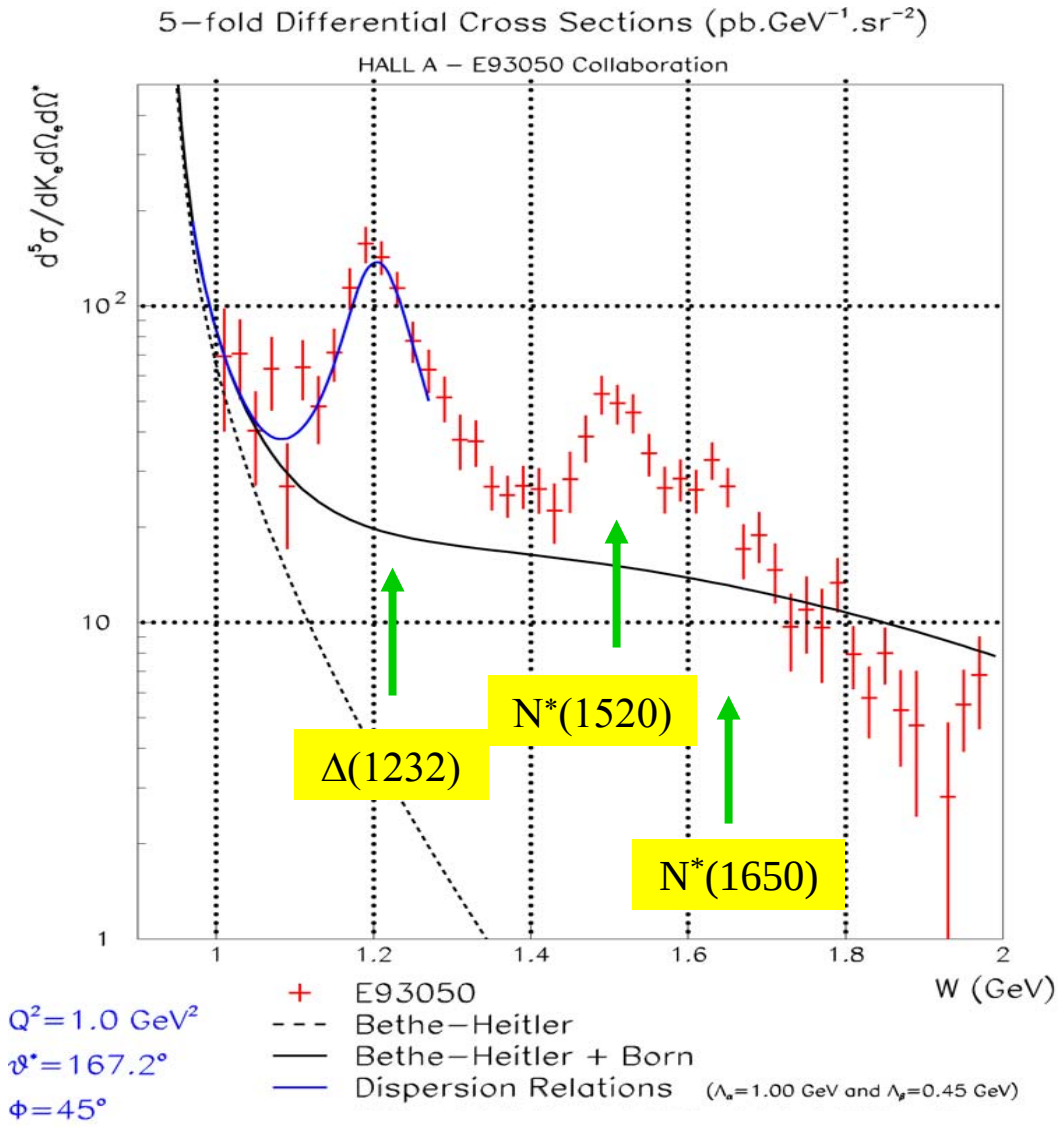
Hall A - E93-50

$ep \longrightarrow ep\gamma$

- 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
  - $\Delta(1232)$, $N^*(1535)$, (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

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It is an exciting time to work in this field !