CLAS Measurement of

$\gamma^* p \rightarrow \Delta(1232) \rightarrow N\pi$

Transition

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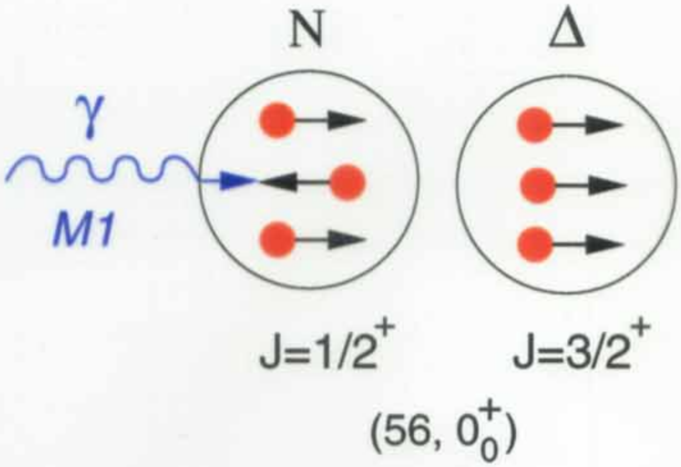
Quadrupole Excitation of P_{33} (1232)

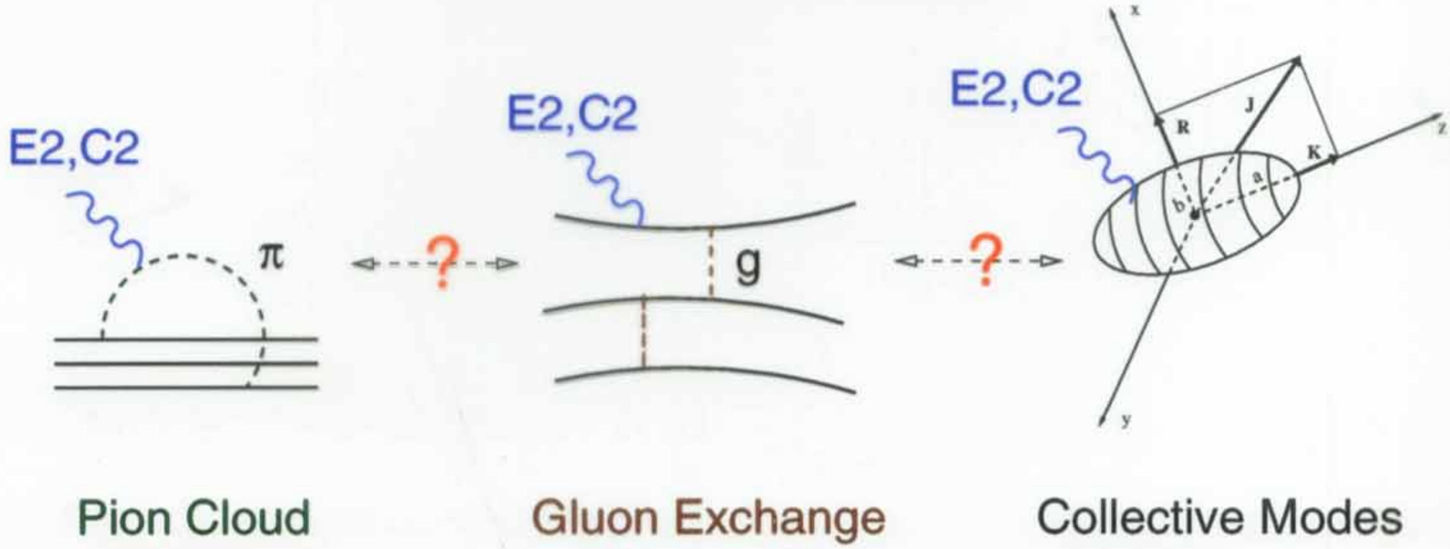
SU(6)

- Spherical symmetry
- Single quark spin flip
- M1 magnetic dipole transition
- E2 = C2 = 0



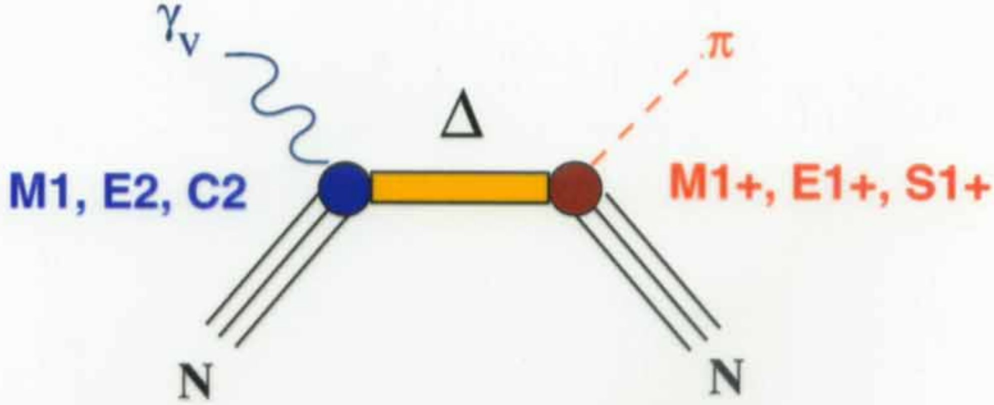
QCD Inspired Models

- SU(6) symmetry broken
- E2, C2 transition possible through a variety of mechanisms:



- Quadrupole N−Δ transition strength and Q^2 evolution strongly constrains models of non−perturbative QCD.

Pion Electroproduction Multipoles



L_γ	γ Multipole	J	l_π	π Multipole	Parity $(-)^{l_\pi+1}$
0	C0	1/2	1	S_{1-}	+
1	E1,C1	1/2	0	E_{0+} S_{0+}	–
		3/2	2	E_{2-} S_{2-}	–
	M1	1/2	1	M_{1-}	+
		3/2	1	M_{1+}	+
2	E2,C2	3/2	1	E_{1+} S_{1+}	+
		5/2	3	E_{3-} S_{3-}	+
	M2	3/2	2	M_{2-}	–
		5/2	2	M_{2+}	–

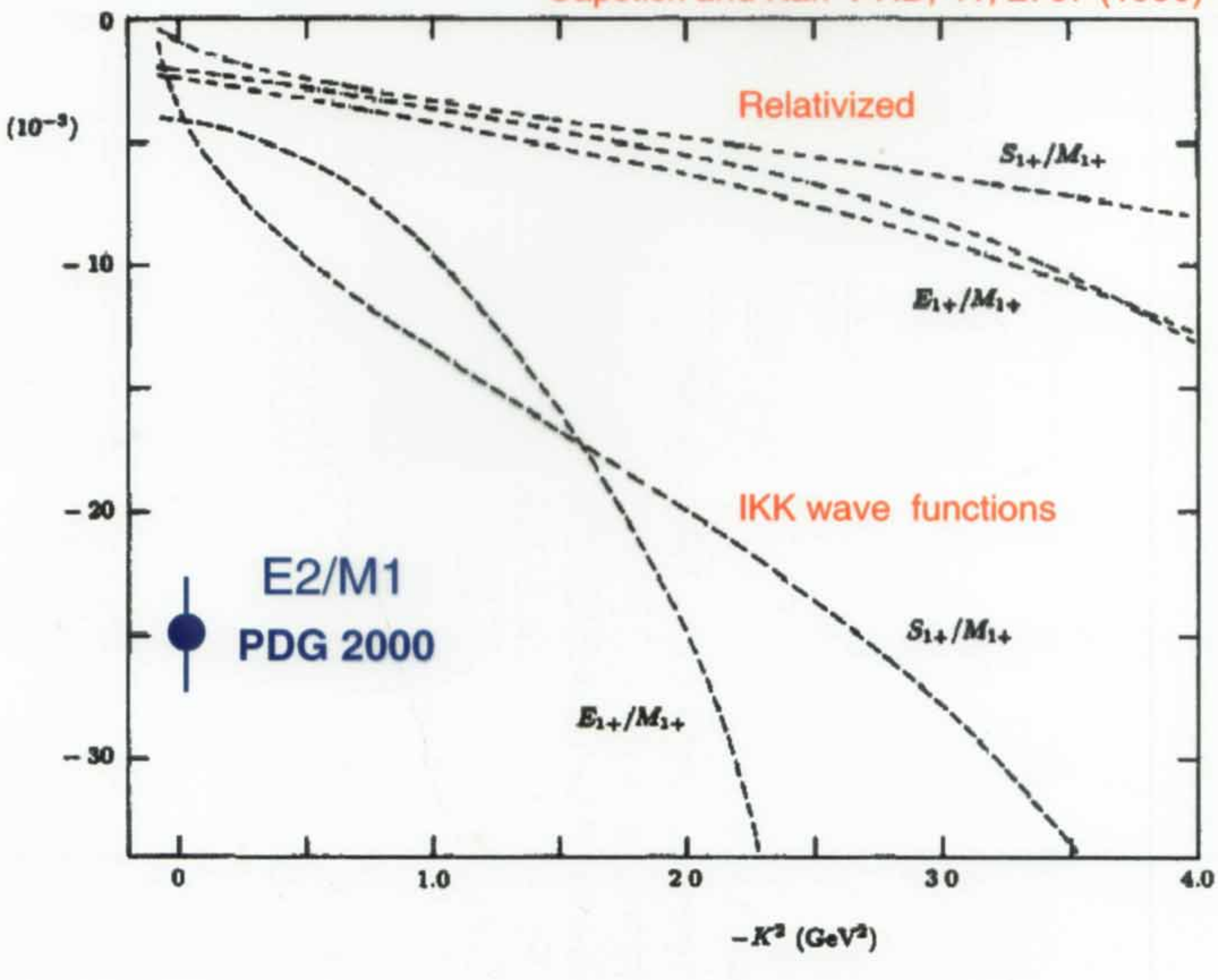
How strong are unitarity corrections to EM couplings?

Quark Model Calculations (circa 1990)

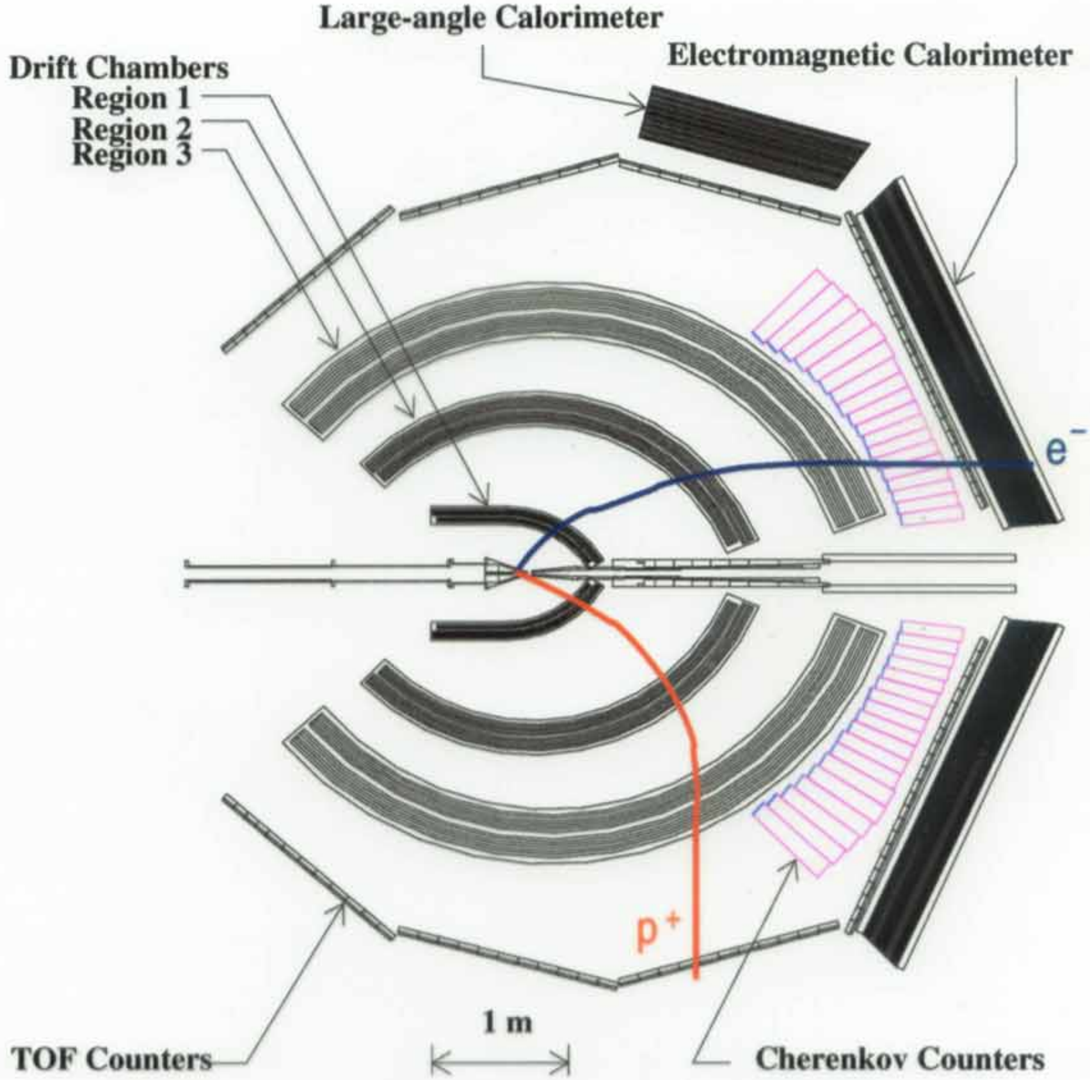
E2 / M1 < 1 % at photon point

Large sensitivity to relativistic corrections and truncation of harmonic oscillator basis

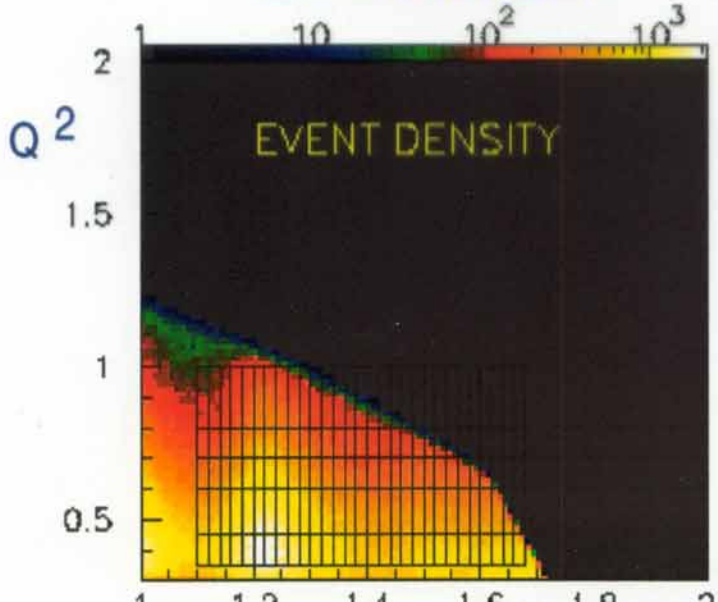
Capstick and Karl PRD, 41, 2767 (1990)



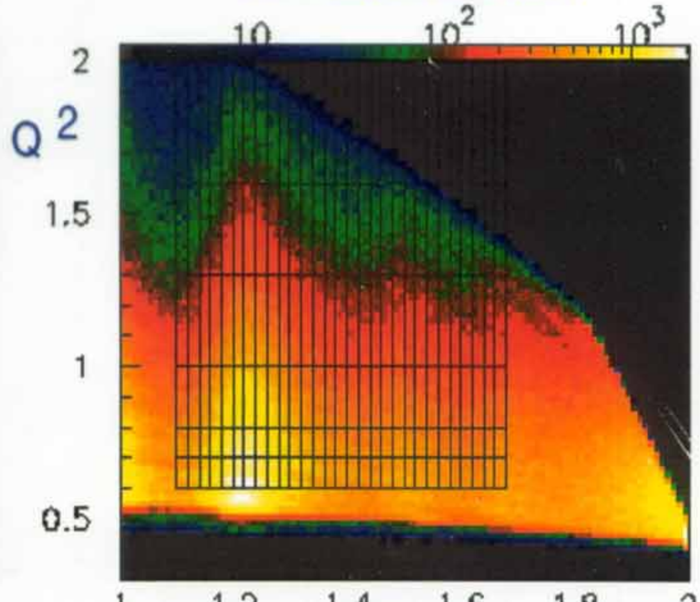
CLAS / Hall B / Jefferson Lab

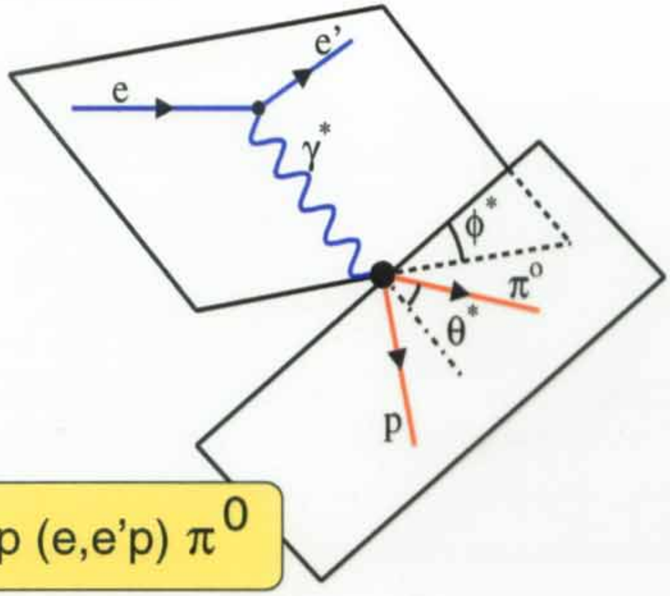


E = 1.645 GeV



E = 2.445 GeV





p (e,e'p) π^0

Structure Functions

Out–of–plane measurement provides access to four structure functions.

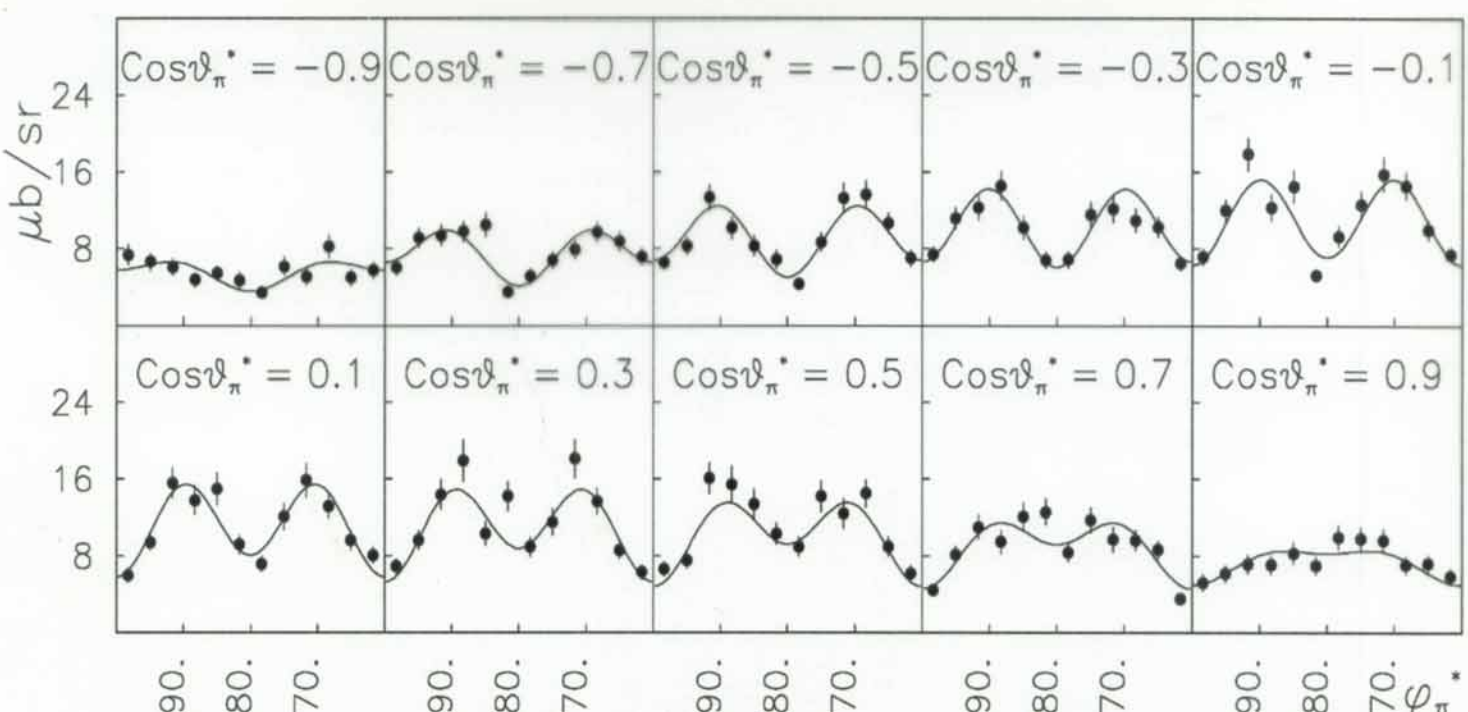
Longitudinal / transverse separation of quadrupole transition possible w/o Rosenbluth method.

$$\frac{d^2\sigma}{d\Omega_\pi^*} = \frac{p_\pi^*}{k_\gamma^*}(\sigma_T + \epsilon_L\sigma_L + \epsilon\,\sigma_{TT}\sin^2\theta_\pi^*\cos 2\phi_\pi^* + \sqrt{2\epsilon_L(\epsilon+1)}\,\sigma_{LT}\sin\theta_\pi^*\cos\phi_\pi^*)$$

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

Structure functions determined from fits to ϕ^* c.m. distributions

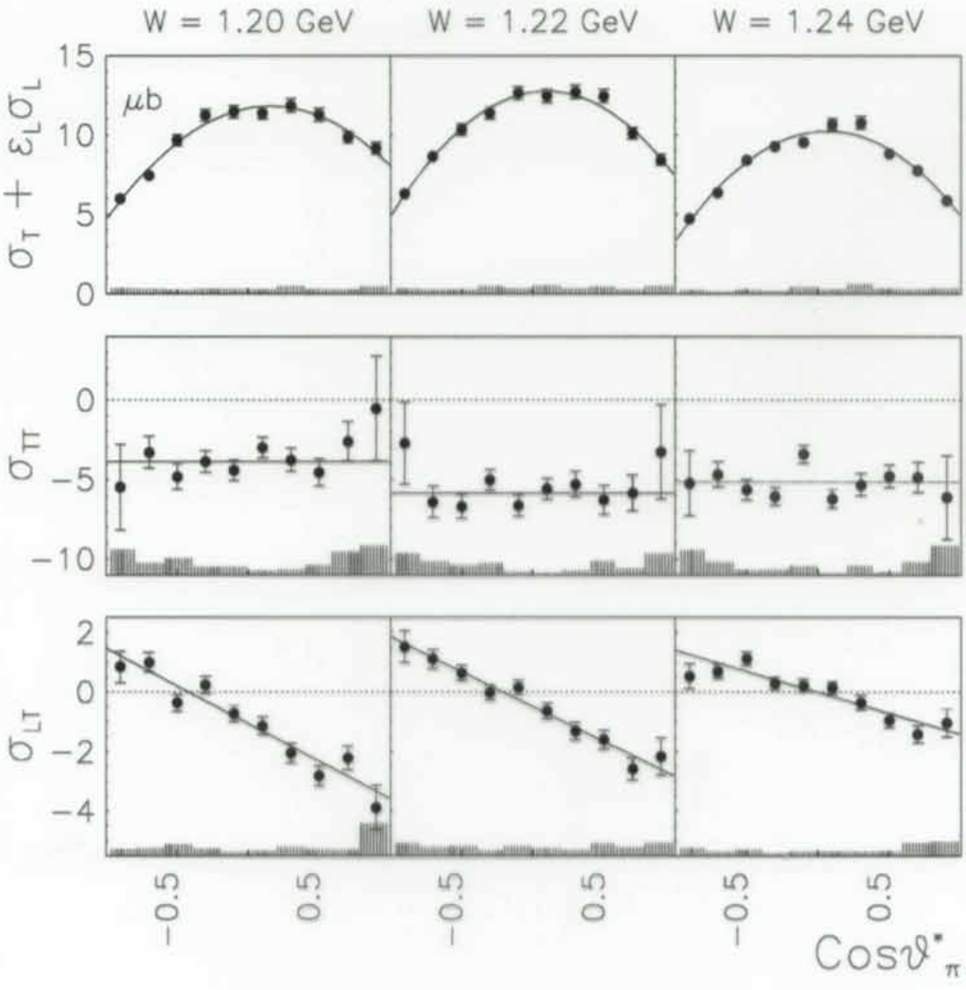
CLAS $Q^2 = 0.9$ GeV ^{2} W=1.22 GeV



Multipole Analysis of Structure Functions

Partial Wave Fit

$$\sigma_T + \epsilon_L \sigma_L = A_0 + A_1 P_1 + A_2 P_2$$
$$\sigma_{TT} = C_0$$
$$\sigma_{LT} = D_0 + D_1 P_1.$$



CLAS
$Q^2 = 0.9$ GeV^2

Multipoles

Resonant

$$|M_{1+}|^2 = A_0/2$$
$$Re(E_{1+} M^*_{1+}) = (A_2 - 2\,C_0/3)/8$$
$$Re(S_{1+} M^*_{1+}) = D_1/6.$$

$\longrightarrow$

$$R_{EM} = Re(E_{1+} M^*_{1+}) \,/\, |M_{1+}|^2$$
$$R_{SM} = Re(S_{1+} M^*_{1+}) \,/\, |M_{1+}|^2$$

Non-Resonant

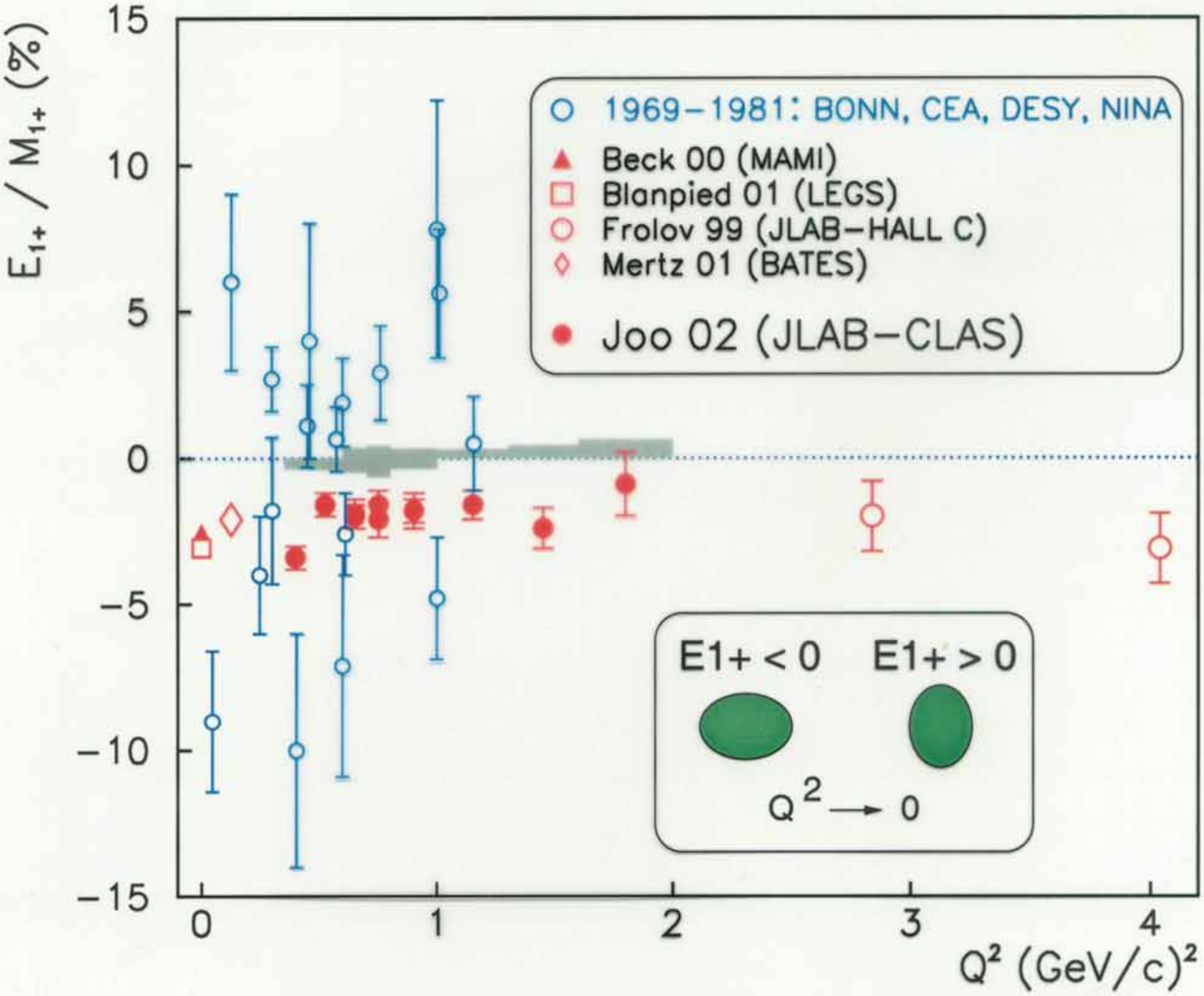
$$Re(E_{0+} M^*_{1+}) = A_1/2$$
$$Re(S_{0+} M^*_{1+}) = D_0$$
$$Re(M_{1-} M^*_{1+}) = -(A_2 + 2\,(A_0 + C_0))/8$$

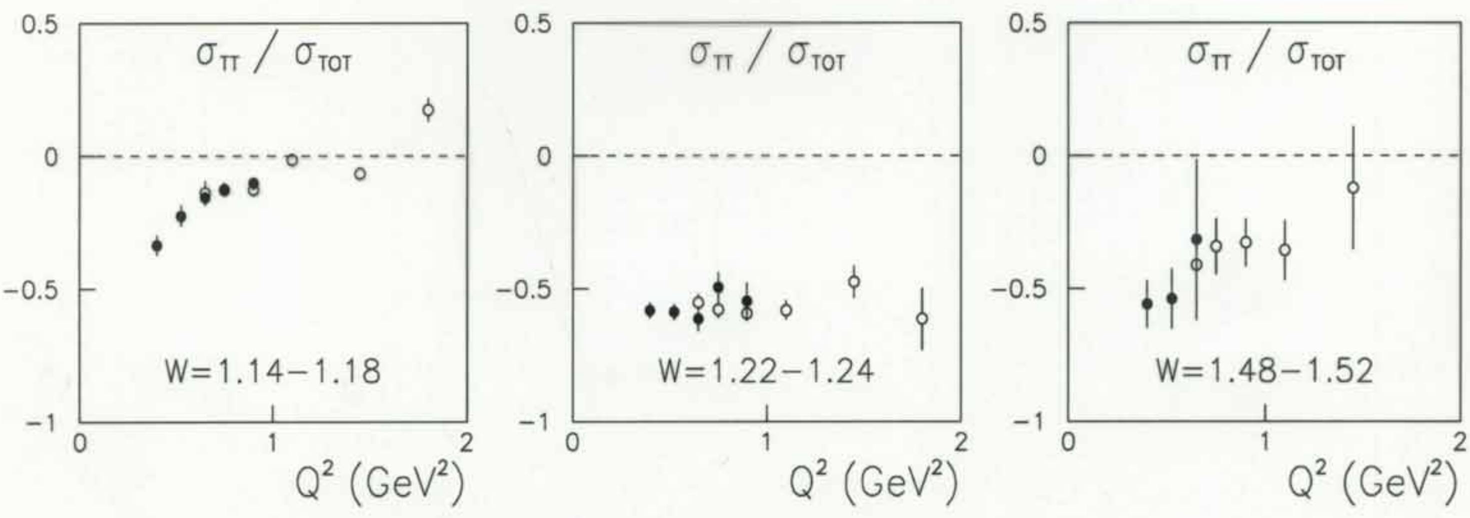
Assumptions:

1. M1 dominance

CLAS Measurement of E1+ Quadrupole NΔ Transition

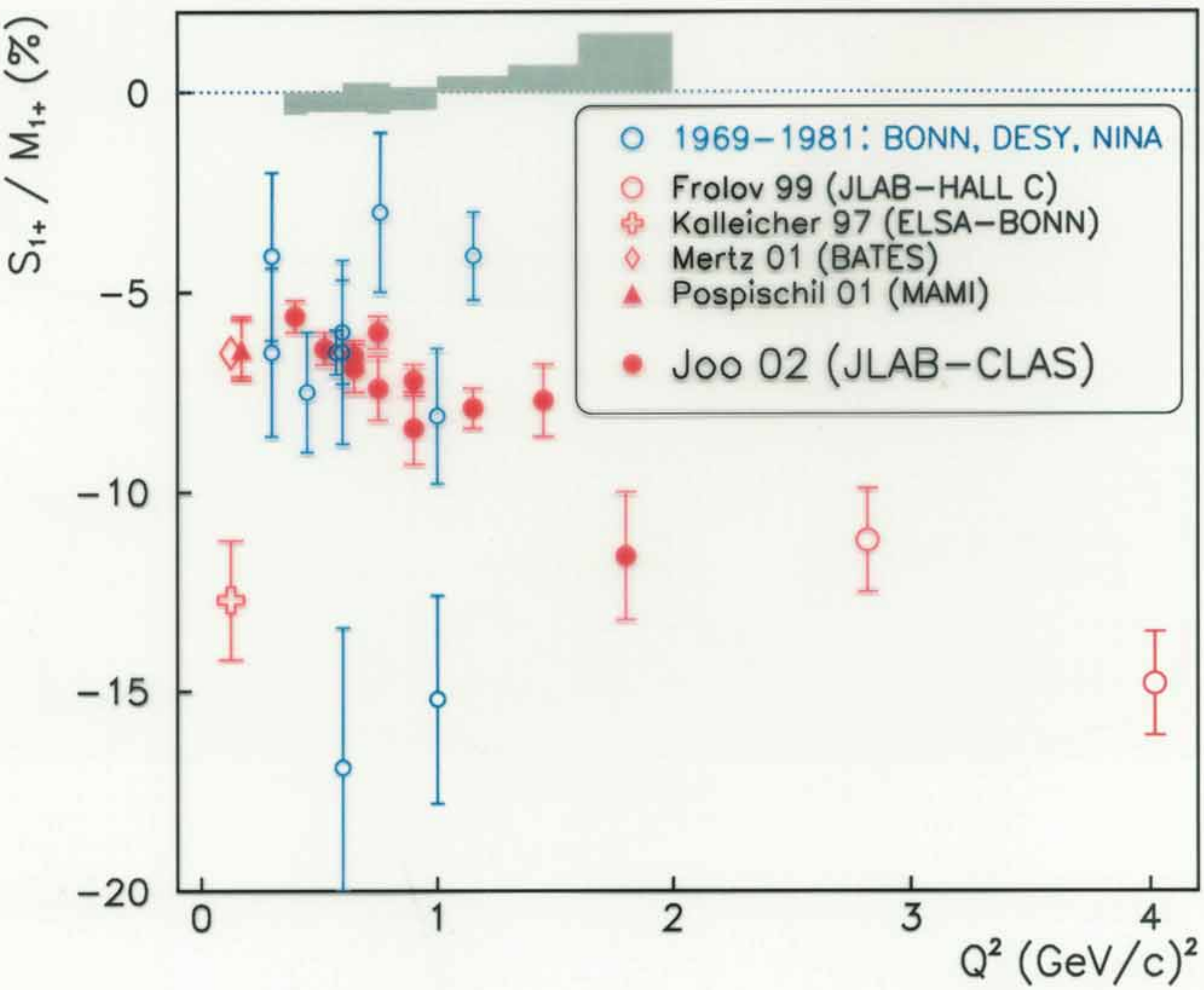
K. Joo et al., PRL, 88, 122001 (2002).





CLAS Measurement of S1+ Quadrupole NΔ Transition

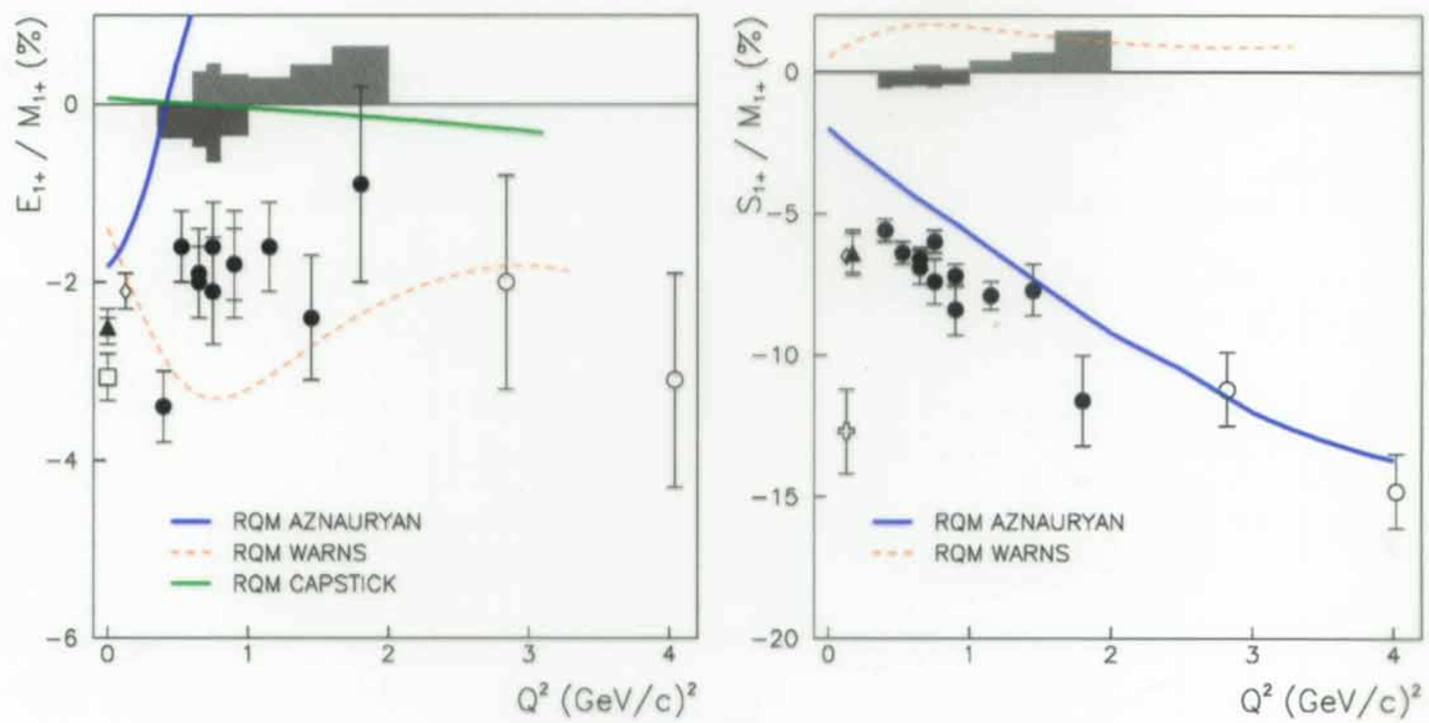
K. Joo et al., PRL, 88, 122001 (2002).



Longitudinal S1+ > Transverse E1+ quadrupole

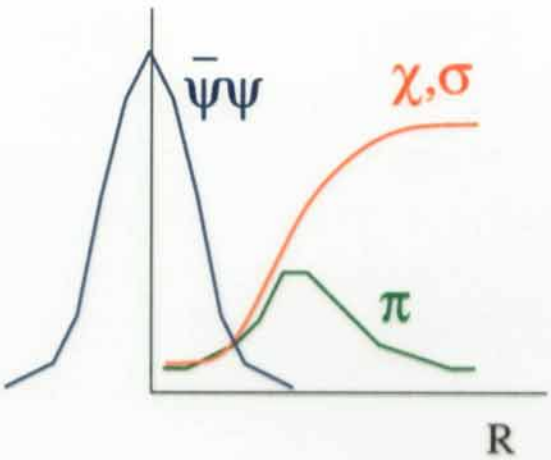
Falls off with Q^2 more slowly than M1+

Relativistic Quark Models (Circa 1993)



Unable to consistently describe both E1+ and S1+ multipoles

Chiral Soliton Models



QCD vacuum color dia–electric medium which excludes color electric field (Meissner effect).

Spontaneous breaking of chiral symmetry requires existence of scalar and pion fields which can act to confine quarks.

Chiral Quark Model (XQM)
(Silva, et al. NPA, 675 (2000) 637)

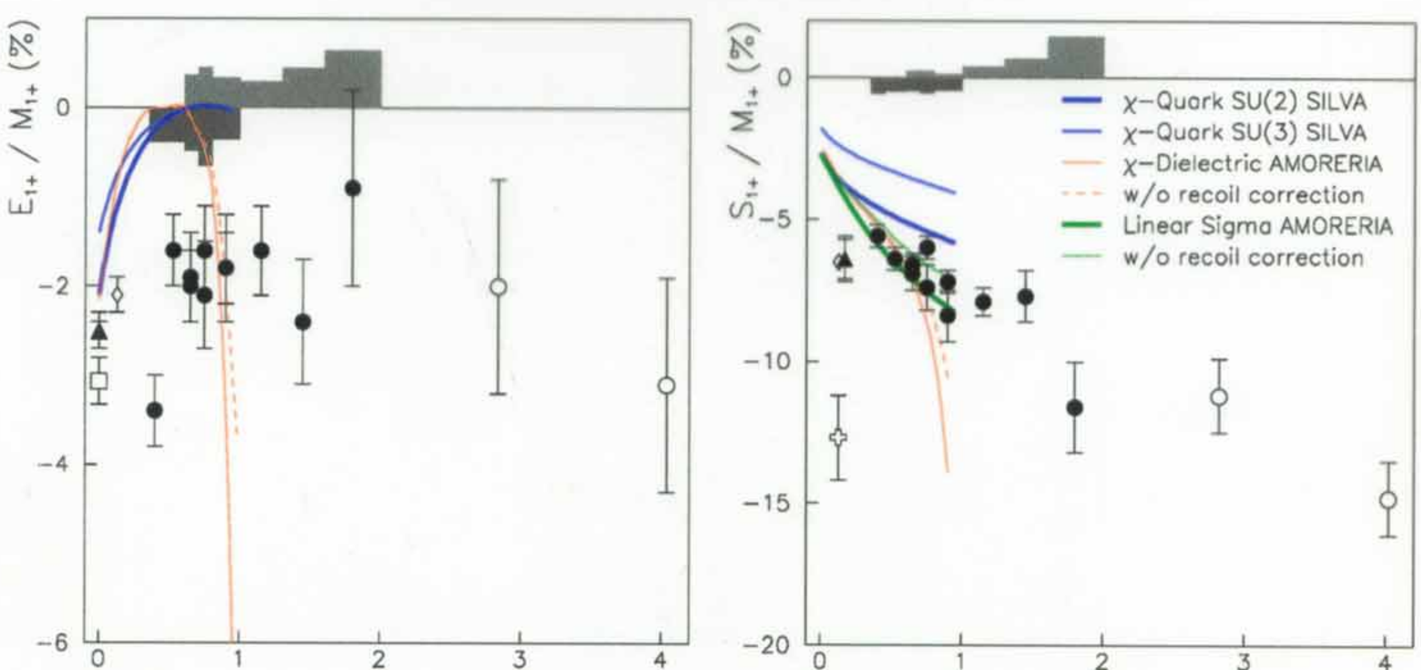
XQM: pion cloud excitations of Dirac sea (e.g. – instantons)

Chiral Chromodielectric Model (CDM)
Linear Sigma Model (LSM)
(Amoreria et al., PRC, 52 (2000) 45202)

CDM: quarks confined at surface of bag.

LSM: strong pion cloud within hadron interior.

Quadrupole NΔ transition dominated by deformed pion field.
Sensitive to details of confinement mechanism.



Lattice QCD (Cyprus–ETH–Wuppertal–Athens–MIT)

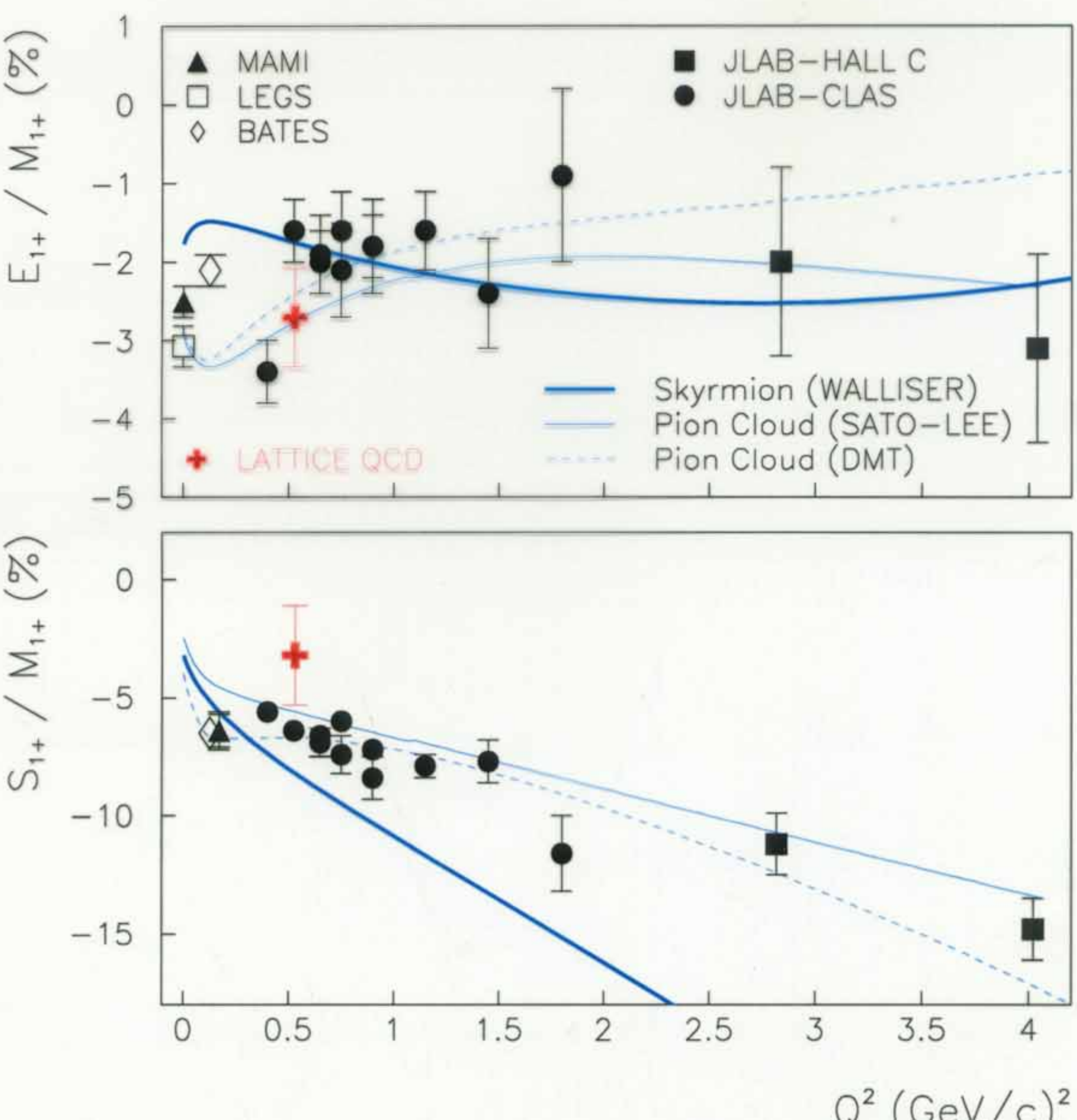
(A. Tsapalis, et al. hep–lat/0209074)

REM(quenched) = –0.9(0.8) %

REM(unquenched) = (–2 to –3) %

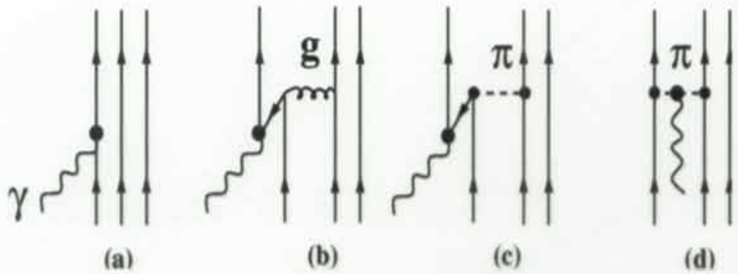
RSM(unquenched) = –3.2 (2.1) %

Unquenching drives ratios more negative.

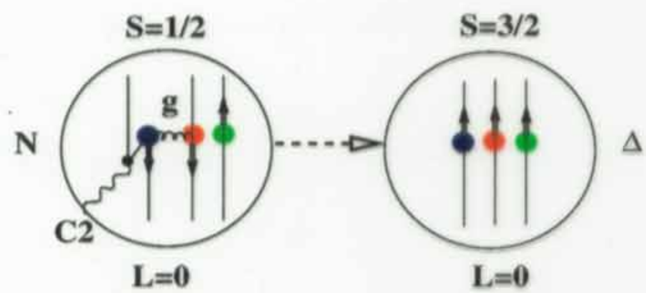


Two–body Exchange Currents

Grabmayr and Buchmann, PRL 86, 2237 (2001)



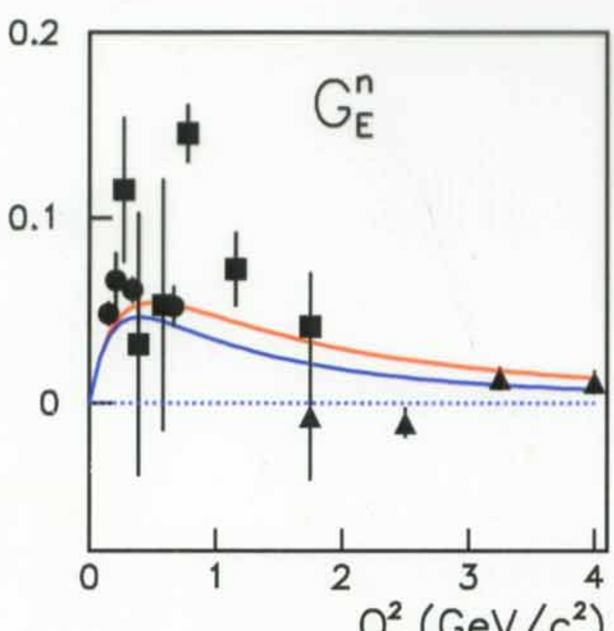
Current conservation requires photon coupling to 2–body d.o.f.

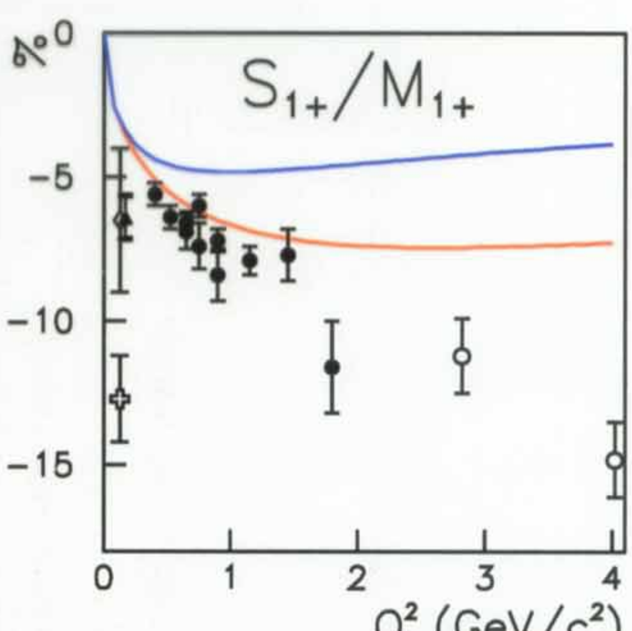


Quadrupole coupling possible through 2–quark spin flip

$$\frac{C2}{M1} = M_N \, \frac{\sqrt{\mathbf{q}^2}}{6} \, \frac{G_{C2}^{N\to\Delta}(\mathbf{q}^2)}{G_{M1}^{N\to\Delta}(\mathbf{q}^2)} = \frac{M_N}{2\sqrt{\mathbf{q}^2}} \, \frac{G_E^n(\mathbf{q}^2)}{G_M^n(\mathbf{q}^2)}$$

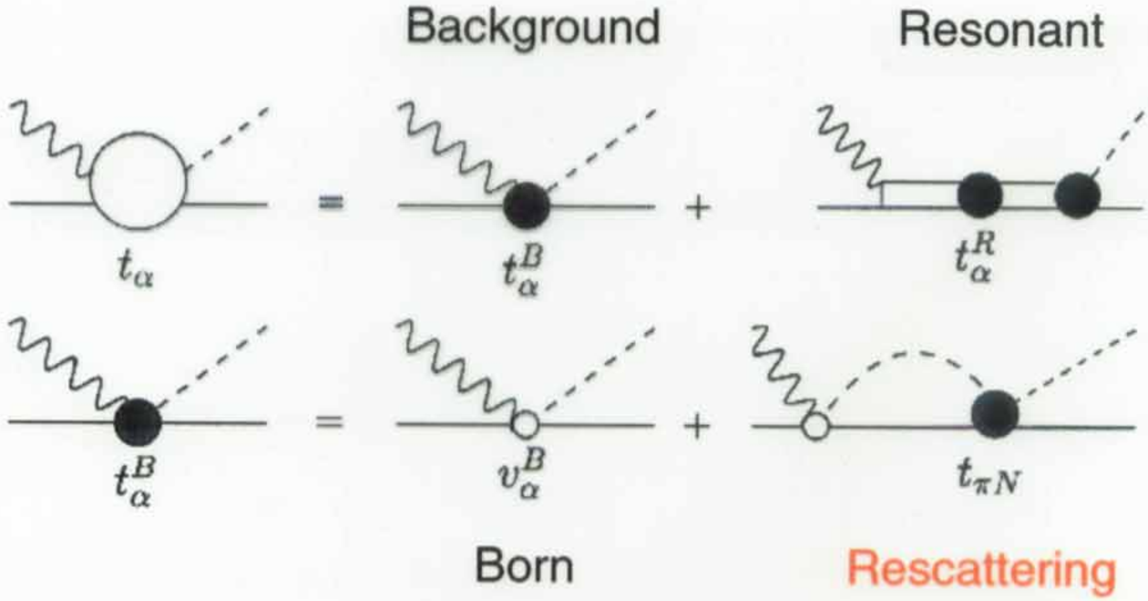
Common mechanism relates neutron charge radius and quadrupole deformation





Phenomenological Models

Mainz Unitary Isobar Model (MAID) – Drechsel et al.
Dubna–Mainz–Taipei (DMT) – Kamalov and Yang
T. Sato and H. Lee

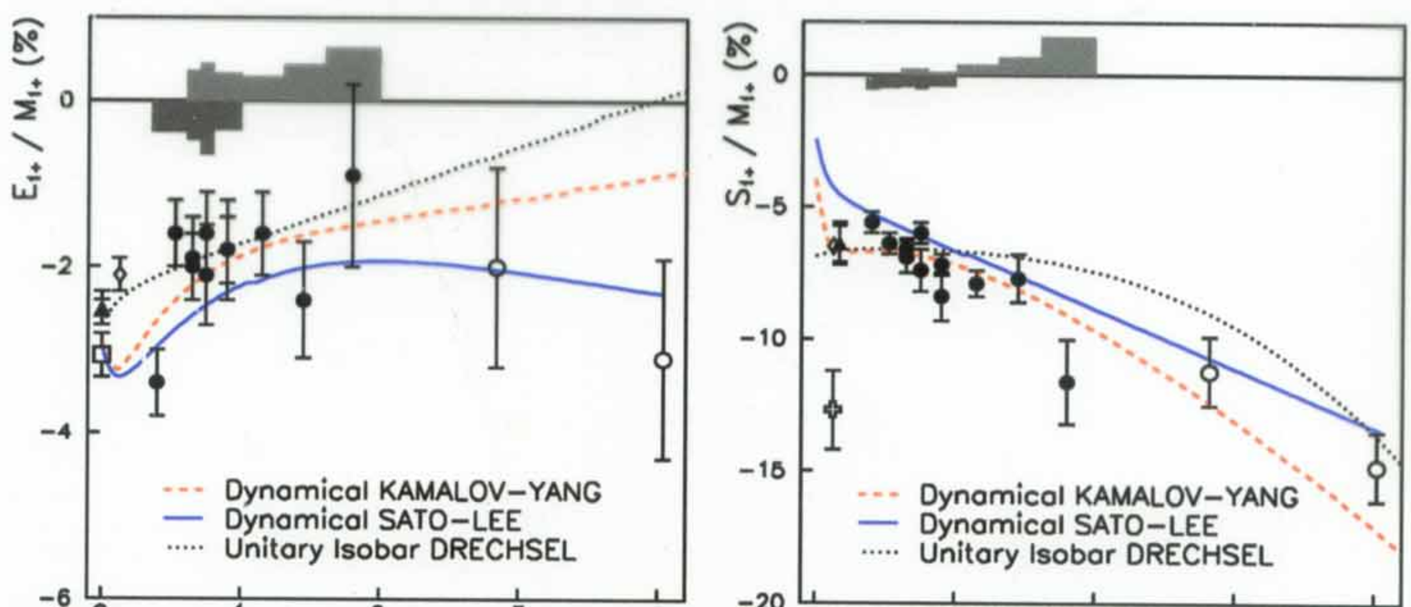


$$t_{\gamma\pi}^{B,\alpha}(\mathrm{MAID}) = \exp\left(i\delta_\alpha\right)\,\cos\delta_\alpha v_{\gamma\pi}^{B,\alpha}(q, W, Q^2)$$

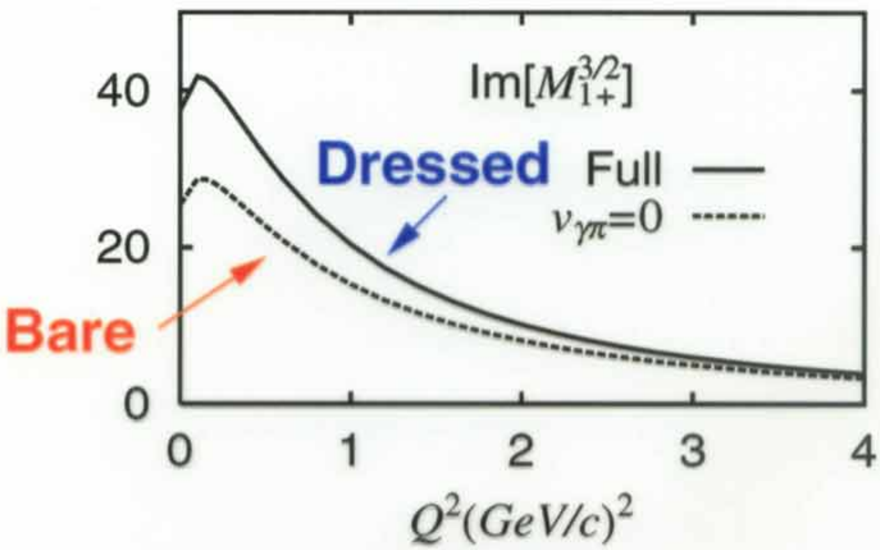
Watson's Theorem

$$t_{\gamma\pi}^{B,\alpha}(DMT) = e^{i\delta_\alpha}\cos\delta_\alpha\left[v_{\gamma\pi}^{B,\alpha} + P\int_0^\infty dq'\,\frac{q'^2\,R_{\pi N}^{(\alpha)}(q_E, q')\,v_{\gamma\pi}^{B,\alpha}(q')}{E - E_{\pi N}(q')}\right]$$

Off–shell pion reaction model



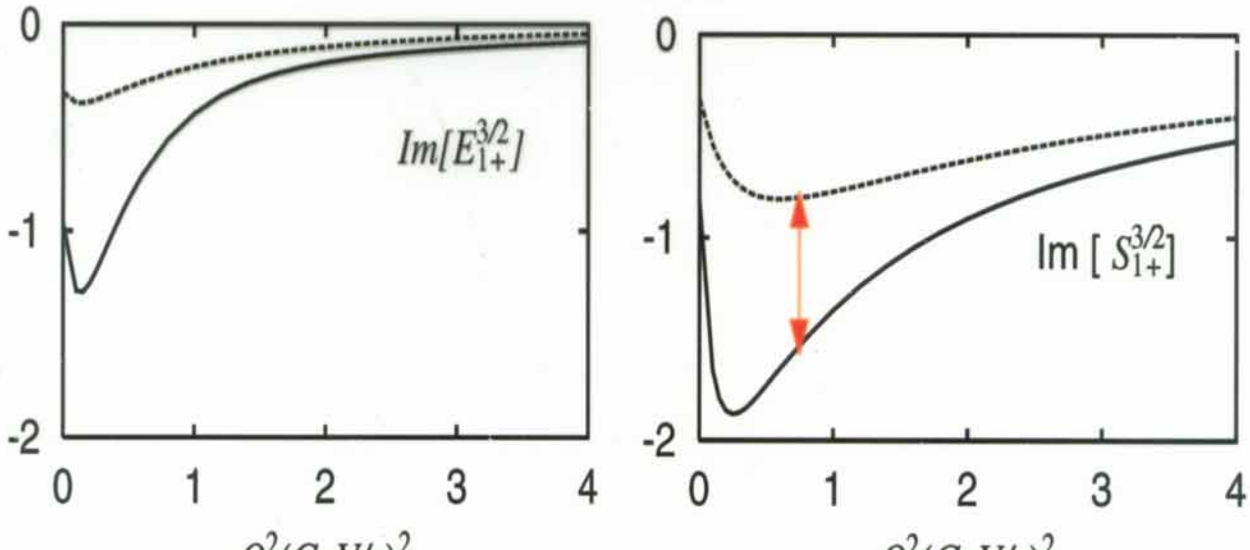
Sato–Lee Dynamical Model



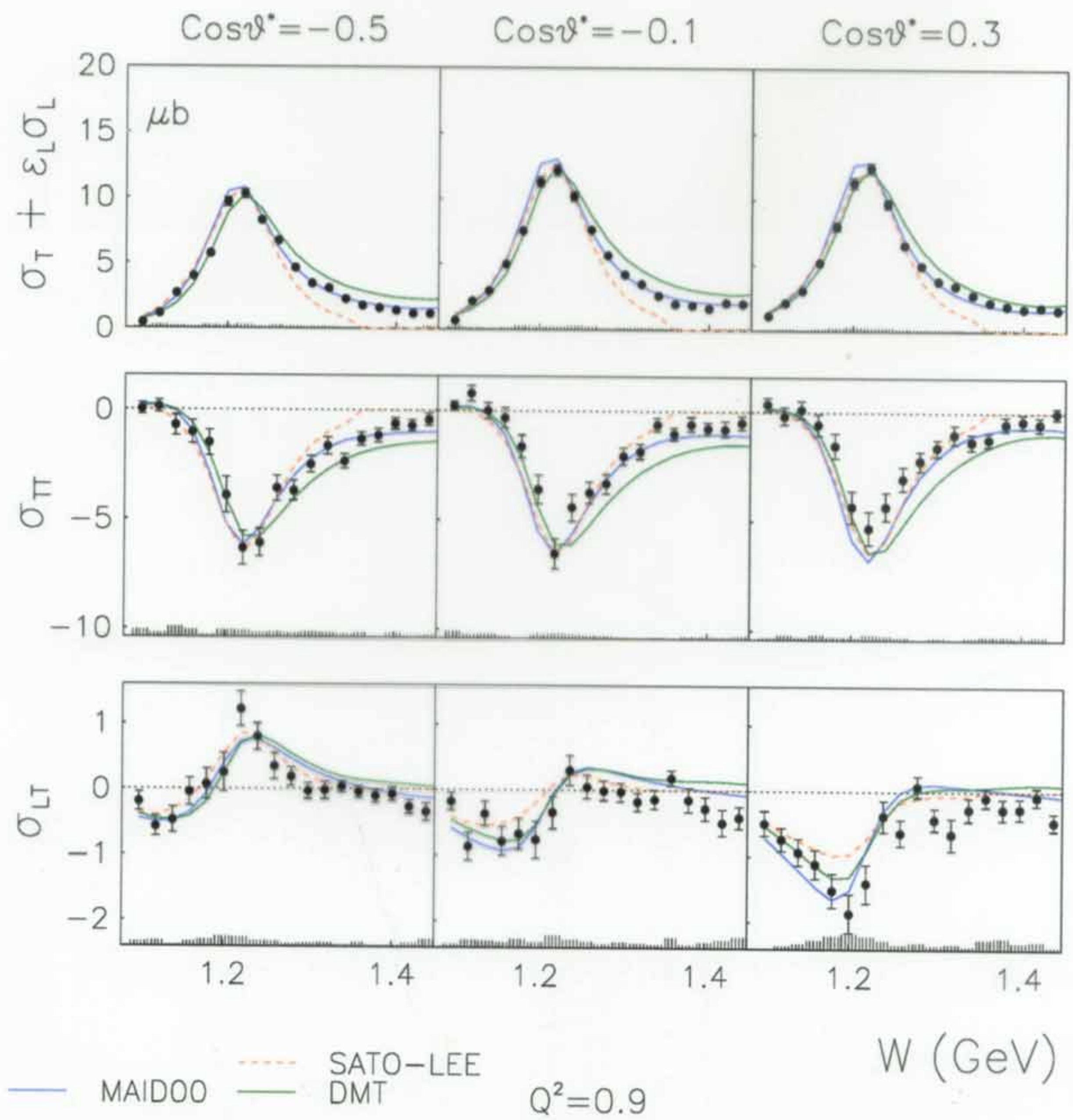
Non–resonant backgrounds contribute 40% of the full "dressed" M1 amplitude.

M1 "bare" photo–coupling close to quark model prediction

Pion rescattering strongly enhances both E1+ and S1+ quadrupole strength at low Q2

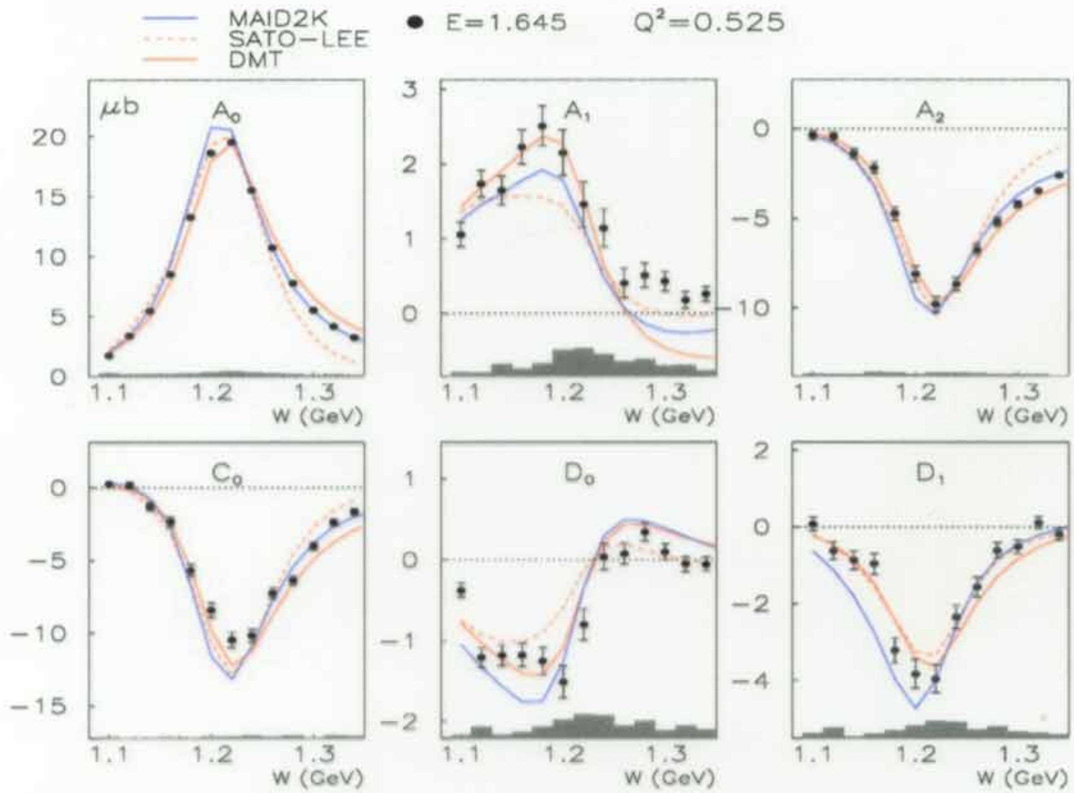


Extracted Structure Functions Compared to Phenomenological Models



Partial Wave Coefficients Compared to Phenomenological Models

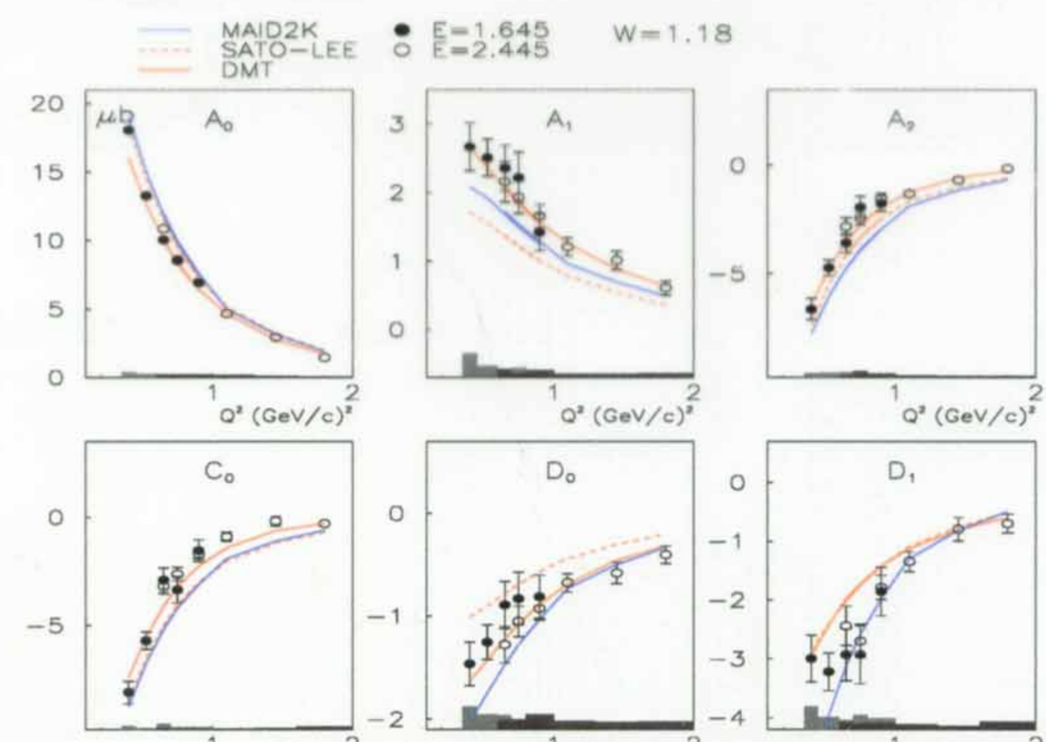
W Dependence



Models in close agreement near peak of Delta(1232).

Large variation in model treatment of backgrounds between threshold and resonance mass W=1232 MeV.

Q^2 Dependence



Off resonance behavior can help constrain unitarization schemes of various models.

Beam Asymmetry

$$A_{LT'} = \frac{d^2\sigma^+ - d^2\sigma^-}{d^2\sigma^+ + d^2\sigma^-} = \frac{\sqrt{2\epsilon_L(1-\epsilon)}\,\sigma_{LT'}\,\sin\theta^*_\pi\,\sin\phi^*_\pi}{\sigma_\circ}$$

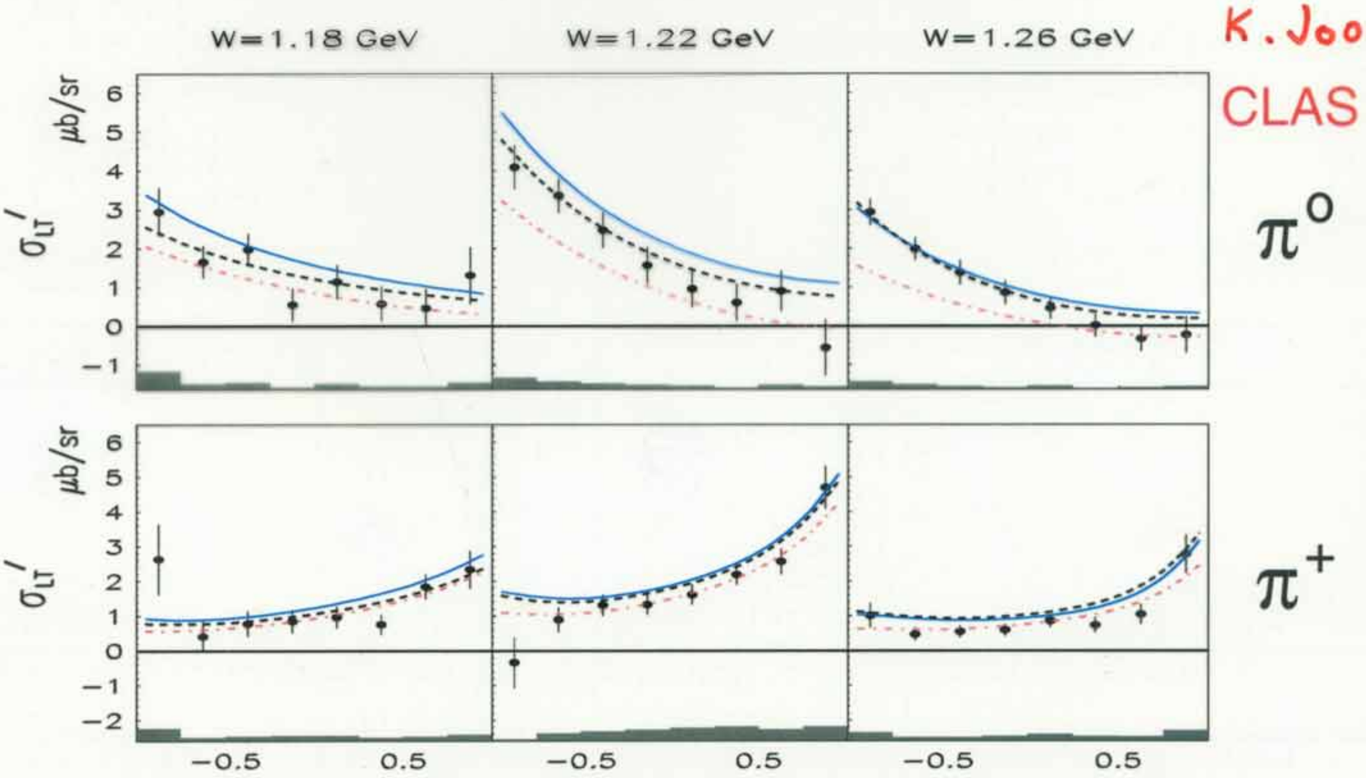
Partial wave expansion of 5th structure function

$$\sigma_{LT'} = D'_0 + D'_1 P_1(\cos\theta^*_\pi) + D'_2 P_2(\cos\theta^*_\pi)$$

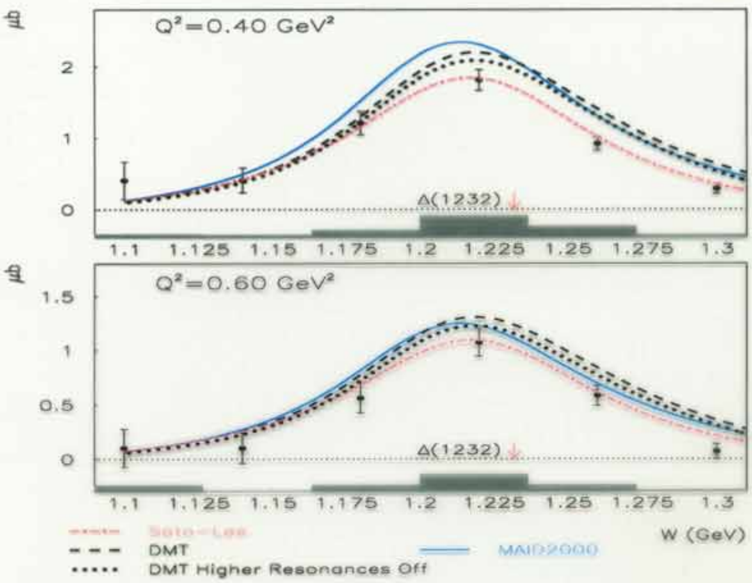
Multipole expansion of Legendre moments

$$\begin{aligned} D'_0 &= -Im((M_{1-} - M_{1+} + 3E_{1+})^* S_{0+} \\ &+ E^*_{0+}(S_{1-} - 2S_{1+}) + ...) \\ D'_1 &= -6Im((M_{1-} - M_{1+} + E_{1+})^* S_{1+} \\ &+ E^*_{1+}S_{1-} + ...) \\ D'_2 &= -12Im((M_{2-} - E_{2-})^* S_{1+} \\ &+ 2E^*_{1+}S_{2-} + ...) \end{aligned}$$

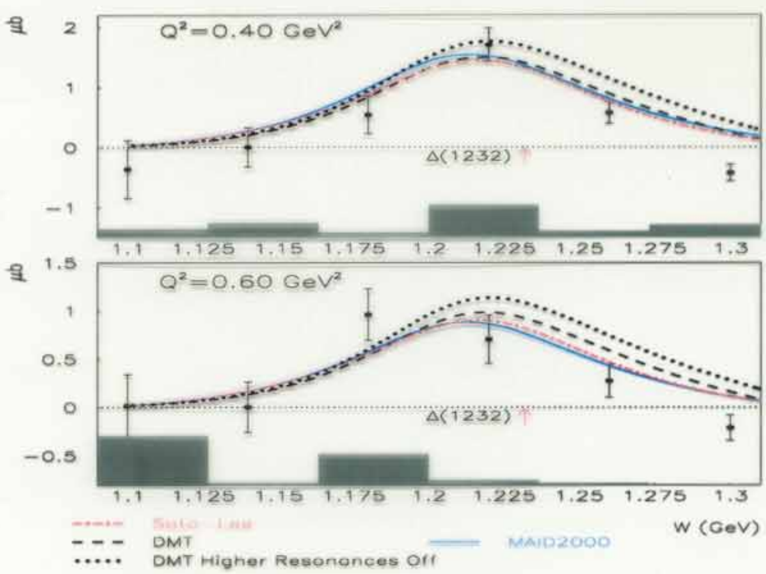
vanishes if final state determined by single complex phase



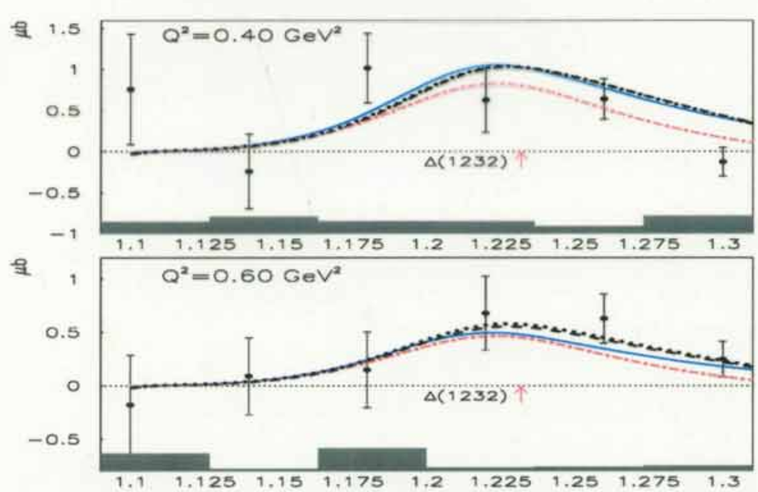
5th Structure Function Legendre Moments for π^+ Electroproduction



D0

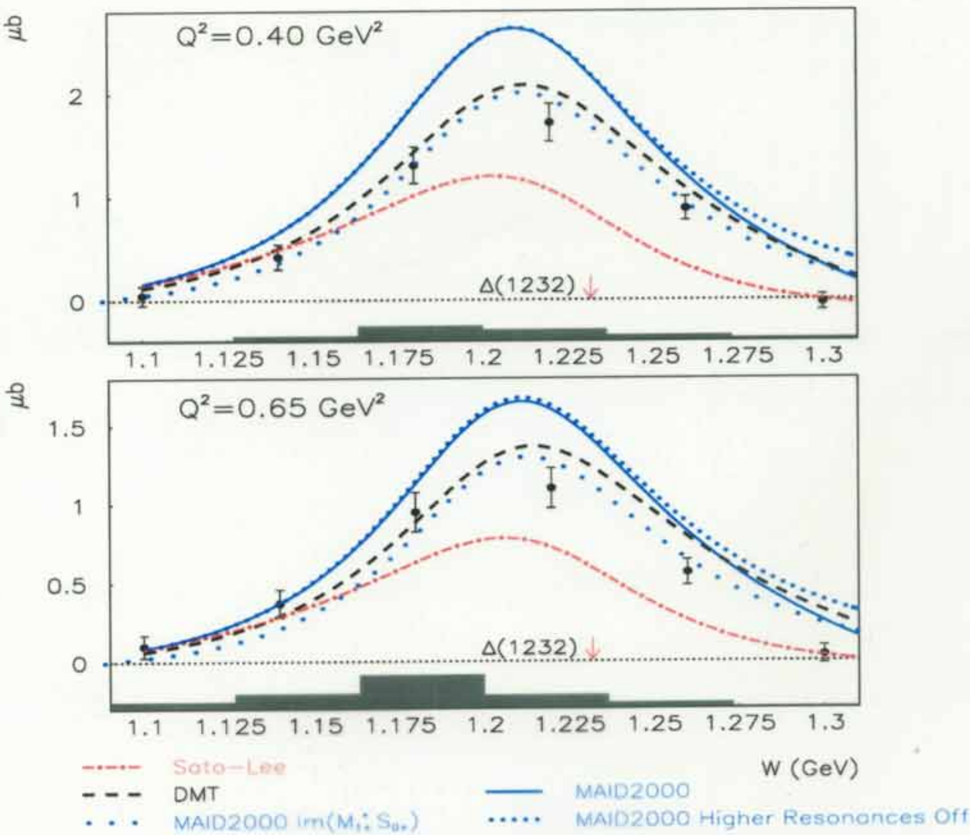


D1

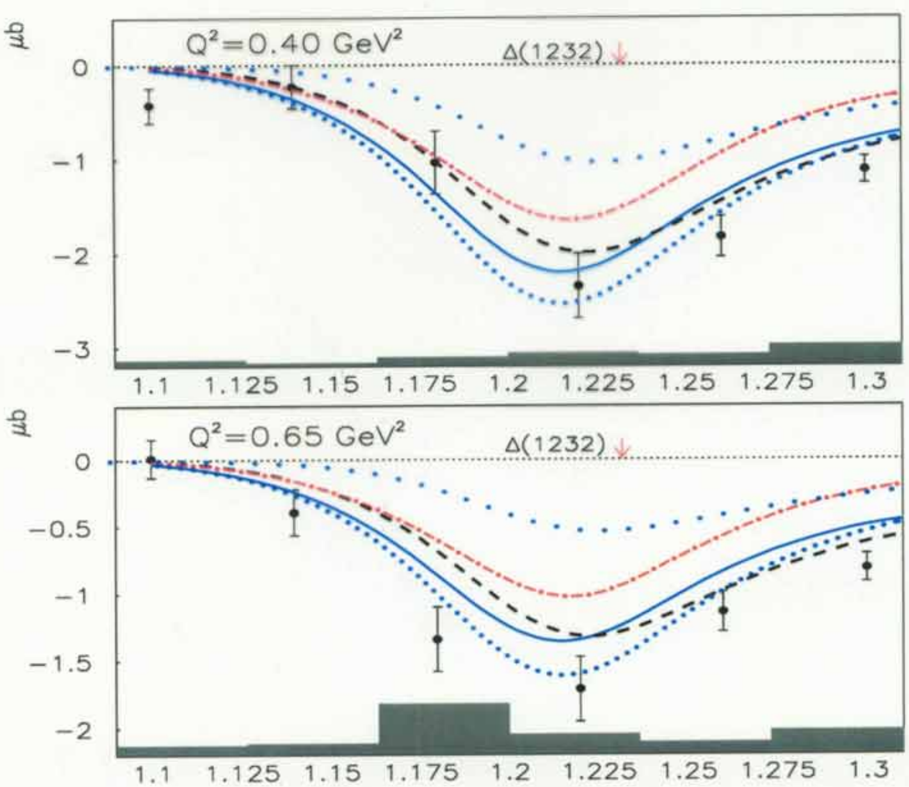


D2

5th Structure Function Legendre Moments for π^o Electroproduction



D0



D1