Electromagnetic Production of Pions in the Resonance Region - Theoretical Aspects

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Motivation

Understand the hadron and nuclear dynamics within QCD

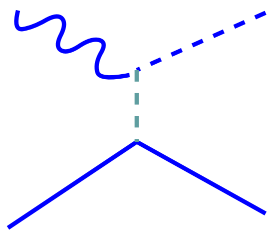
Probe the quark-substructure of hadrons with GeV photons and electrons investigating N^* excitations

Consider photo-pion production mechanism

Δ and N^* in Meson-Baryon continuum

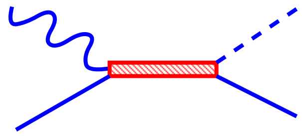
Two reaction mechanisms:

Fast



Particle Exchange

Time delayed



Resonance

- Reaction amplitudes must have the following form

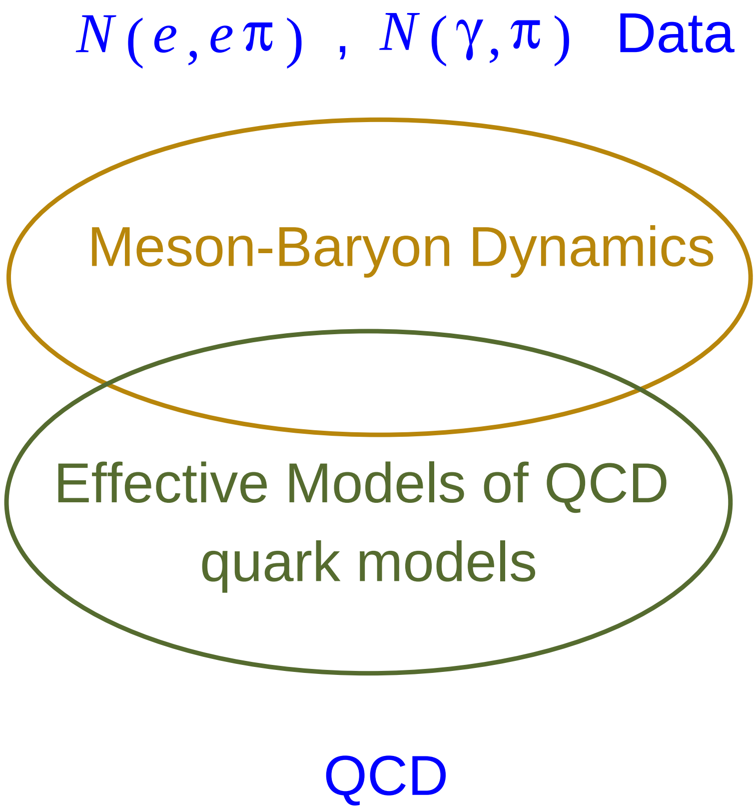
$$T(E) = t_{bg}(E) + t_{res}(E)$$

$t_{bg}(E)$: amplitude due to direct processes

- Unitary Condition $T^\dagger T \sim Im[T]$

t_{bg} and t_{res} are related

Example: πN $t_{res} \sim e^{i(\delta+\delta_{bg})}|t_{res}|$



- Brief review of theoretical approaches
- $\gamma N \to \pi N$ and $N(e,e'\pi)$ Reaction at Δ Region
- Summary

Theoretical Approaches:

- Dispersion Relations

  Introduced by Chew, Goldberg, Low Nambu in 1950's

  Recently Mainz Group for $\gamma N \rightarrow \pi N$ for $E_\gamma < 400 MeV$

- Effective Lagrangian Approaches

  RPI,Mainz(MAID),Giessen-GW(multi-channel)

  t_{bg} : tree-diagram of effective Lagrangian

  t_{res} : Isobar Model

  Unitarization : K-matrix approaches

- Dynamical Approaches

  Tanabe-Ohta, Yang, Nozawa-Blenkleider-Lee, Gross-Surya, Julich Group, Sato-Lee(SL), Kamalov-Yang (DMT)

  Solve dynamical scattering equations with interactions defined by effective Hamiltonian and/or hadron models

Effective Lagrangian Approaches

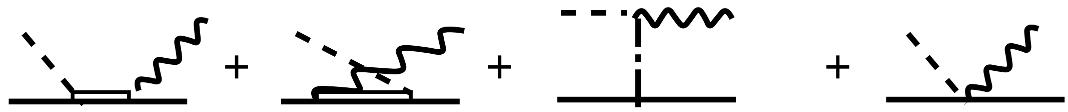
$$T = V + VG_0T \qquad K = V + V Re(G_0)K$$

$$T^{on}_{fi} = \sum_n \left(\frac{1}{1 - iK^{on}}\right)_{fn} K^{on}_{ni}$$

$K \sim V$ and first order EM

$$\boxed{T^{on}_{\pi,\gamma} = \sum_n \left(\frac{1}{1 - iV^{on}}\right)_{\pi,n} V^{on}_{n\gamma}}$$

V γ π =



- Giesen-GW

  Multi channels and resonances

  $$n = \pi N, \pi\pi(\zeta)N, \eta N, K\Lambda \quad + \quad \Delta, N^*$$

- MAID

$$T^{on}_{\pi,\gamma} = (1 - iT_{on})_{\pi,\pi} V^{BG}_{\pi\gamma} + \sum_r T^r(BW)$$

$$T^r(BW) = A^r(Q^2) \frac{f_{\gamma r}(E)\Gamma_r M_r f_{\pi r}(E)}{M_r^2 - E^2 - iM_r\Gamma_r} e^{i\phi_r(E)}$$

$$n = \pi N, \qquad \eta_{\pi N} e^{2i\delta_{\pi N}} \to T^{on}_{\pi N}$$

Dynamical Approach (SL)

- Define a Hamiltonian for $M + B \leftrightarrow B$ transitions
  M: $\gamma, \pi, \rho, \omega$.. B: $N, \Delta, N^*, ..$
  Coupling constants calculated from a hadron model

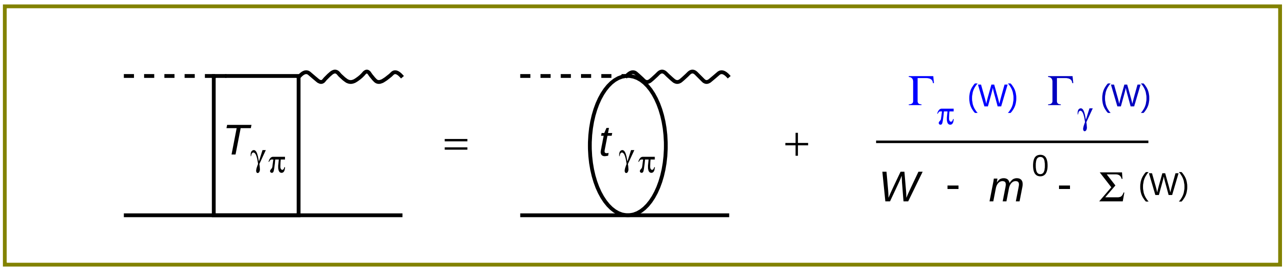
- Apply unitary transformation method to eliminate 'off shell process'

$$H_{eff} = H_0 + v_{bg} + \gamma_{\Delta \leftrightarrow MN}$$

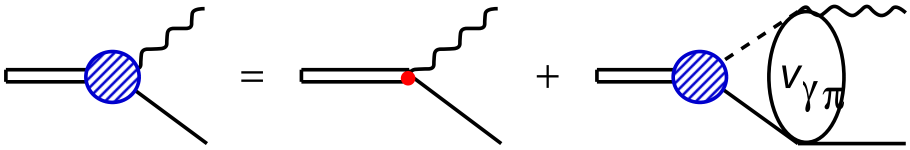
  v_{bg} : energy independent non-resonant interactions

- Derive a reaction model from H_{eff} for meson nucleon reactions
  Dynamical equations in a "finite" Fock space:a solvable few-body problem

Pion Production Amplitude



with



$$\Gamma_\gamma \quad = \quad \gamma_\gamma \quad + \quad \int \Gamma_\pi G_0 v_{\gamma\pi}$$

Dressed Bare

Compare with other works

$$T_{\gamma\pi} \; = \; e^{i\delta} \cos\delta [v_{\gamma\pi} + \int K_{\pi N} Re(G_0) v_{\gamma\pi}] + \frac{\Gamma_\pi \gamma_\gamma}{E - m^0 - \Sigma}$$

- DMT O O $T(BW)$
- MAID O $T(BW)$

$N(\gamma, \pi)$ and $N(e, e'\pi)$ at Δ_{33} Region

Main issues of $\gamma + N \rightarrow \Delta$

- Magnetic dipole coupling and Q^2 evolution
- Is Δ deformed?

Dynamical approach of SL: Can describe extensive data

- πN scattering [Fitted]
- $\gamma N \rightarrow \pi N$ LEGS, Mainz
  [Extract G_M, G_E of $\gamma N \rightarrow \Delta$]
- $N(e, e'\pi)$ Jlab, MIT-Bates, Mainz, NIKHEF [Q^2]

$(e, e'\pi)$ Differential Cross Section

$$\frac{d\sigma^v}{d\Omega} = A + B\cos\phi_\pi + C\cos 2\phi_\pi + h_e D\sin\phi_\pi$$

$$A = \frac{d\sigma_T}{d\Omega} + \epsilon\frac{d\sigma_L}{d\Omega} \qquad B = \sqrt{2\epsilon(\epsilon+1)}\frac{d\sigma_{LT}}{d\Omega}$$

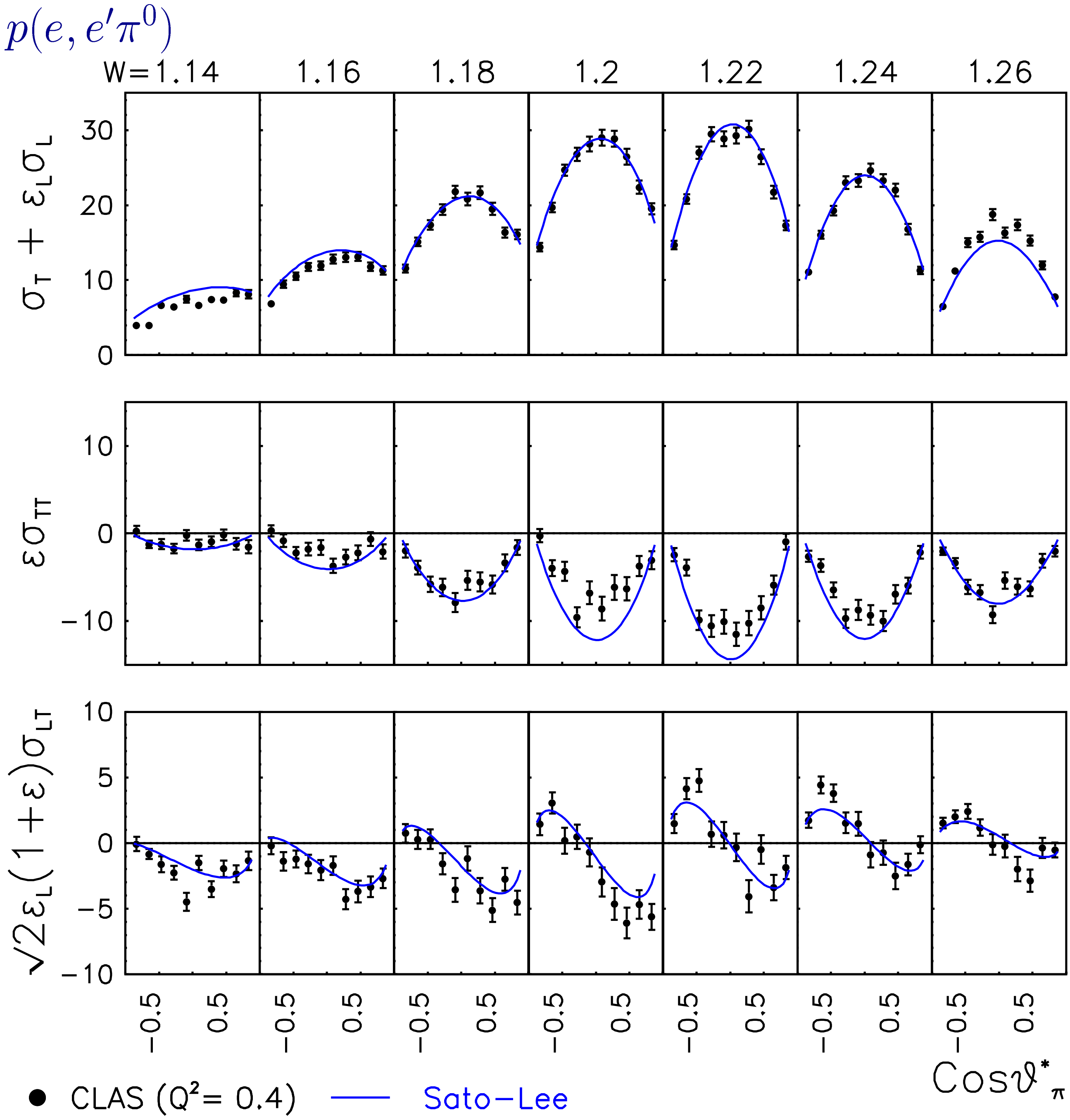
$$C = \epsilon\frac{d\sigma_{TT}}{d\Omega} \qquad D = \sqrt{2\epsilon(1-\epsilon)}\frac{d\sigma_{LT'}}{d\Omega}$$

$(e, e'\pi)$

- A, B, C
- $A_{LT} \sim \sigma_{LT} \sim Re(S_{1+}M^*_{1+})$

$(\vec{e}, e'\pi)$

- $A_{LT'} \sim \sigma_{LT'} \sim Im(S_{1+}M^*_{1+})$



Jlab from Joo

$p(e, e'\pi^+)$ $W = 1230 MeV$

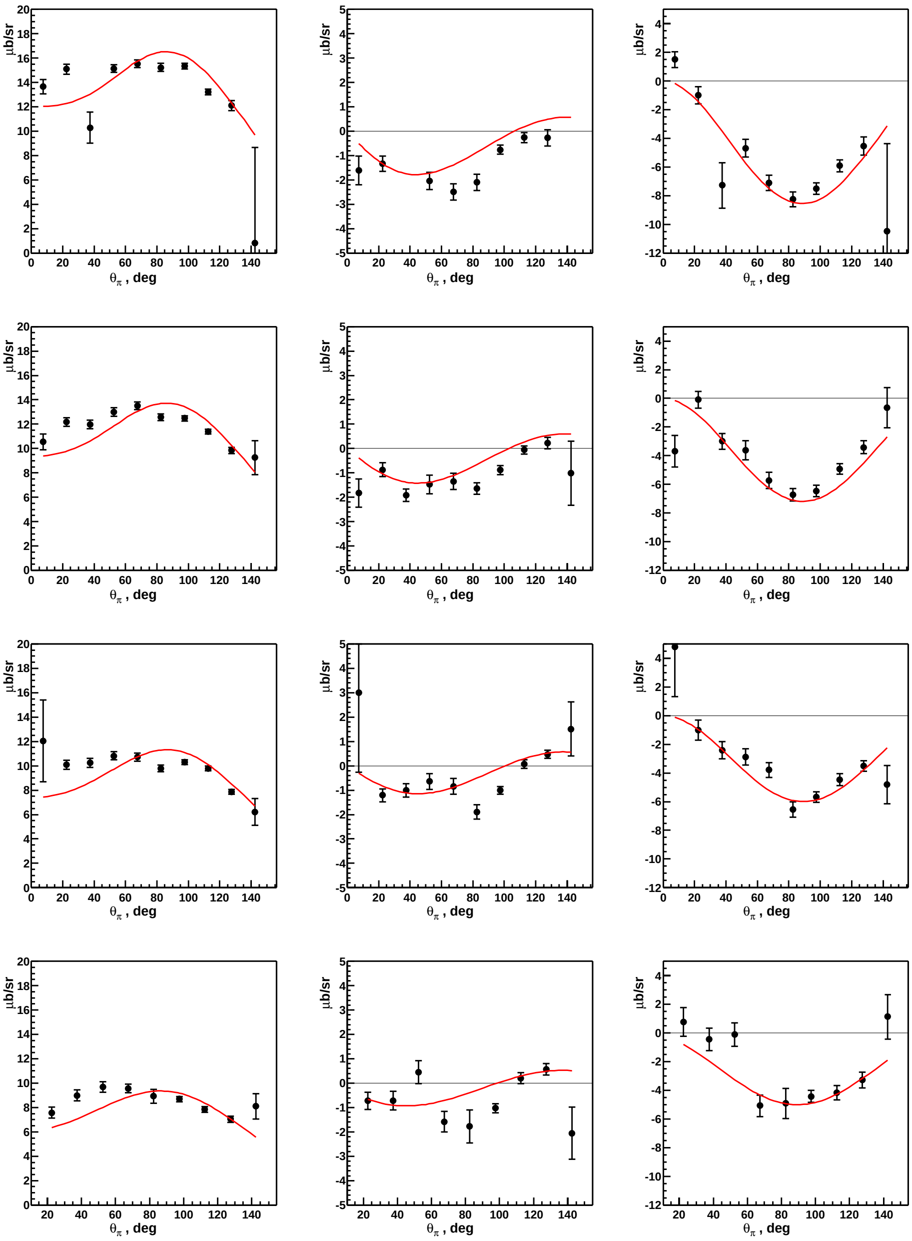
$\sigma_T + \epsilon\sigma_L$ σ_{LT} σ_{TT}

$Q^2 = 0.3$

0.4

0.5

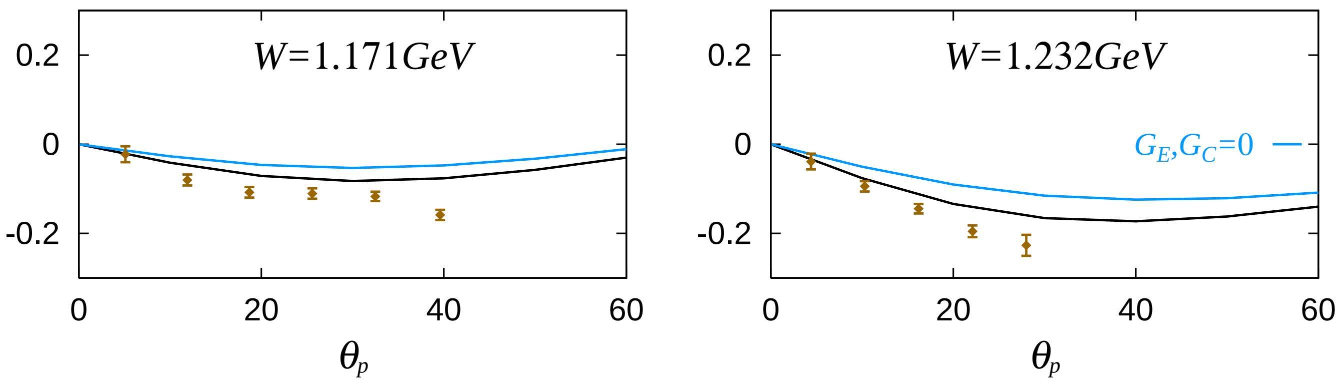
0.6



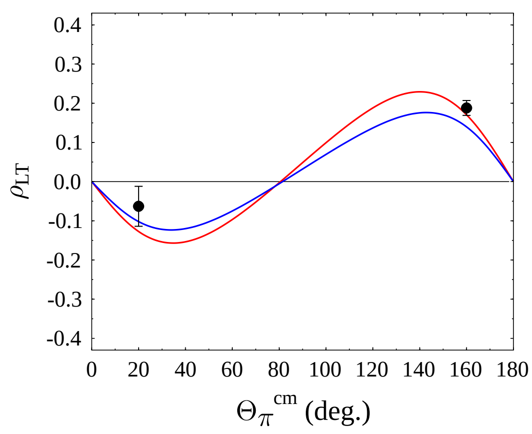
JLAB from Egiyan

A_{LT}

$Q^2 = 0.126(GeV/c)^2$ MIT-Bates C.Mertz et al.



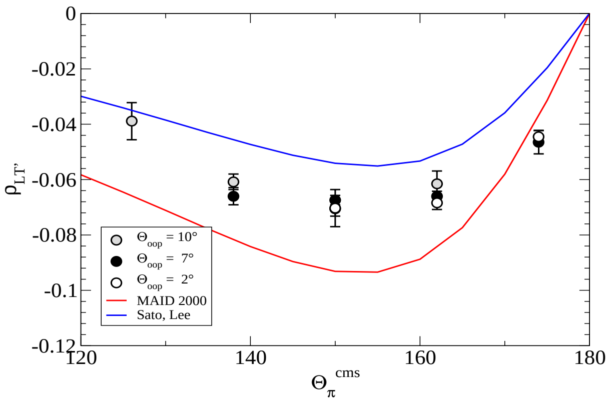
$Q^2 = 0.2(GeV/c)^2$ $W = 1232 MeV$ Mainz
from H. Schmieden (PRELIMINARY)



SL MAID

$A_{LT'}$

$Q^2 = 0.2(GeV/c)^2$ $W = 1232MeV$ Mainz
from H. Schmieden (PRELIMINARY)



SL MAID

K. Joo (NSTAR 2001)

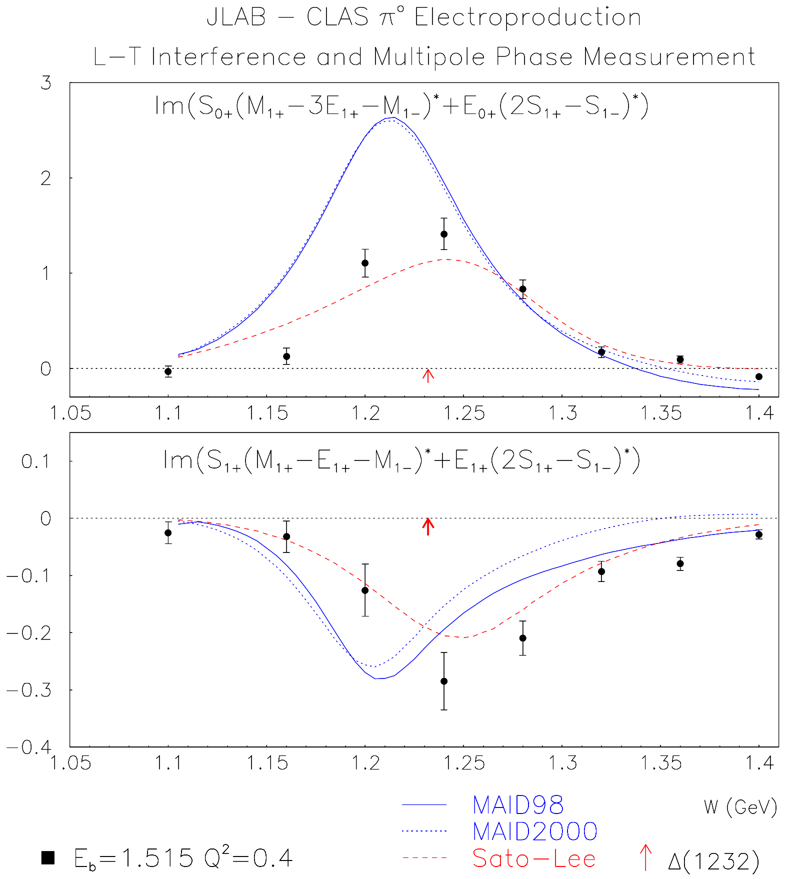


Figure 2. Top figure: D_0' in μb as a function of W (GeV). Bottom figure: D_1' in μb as a function of W (GeV) at Q^2= 0.4 GeV^2. Error bars are statistical only. Results are very preliminary.

MAID SL

$\gamma N \rightarrow \Delta$

$$\Gamma_{\gamma N \rightarrow \Delta} \;=\; \gamma_{\gamma N \rightarrow \Delta} + \int \Gamma_{\pi N \rightarrow \Delta} G_0 v_{\gamma \pi}$$

dressed and bare form factors have been extracted

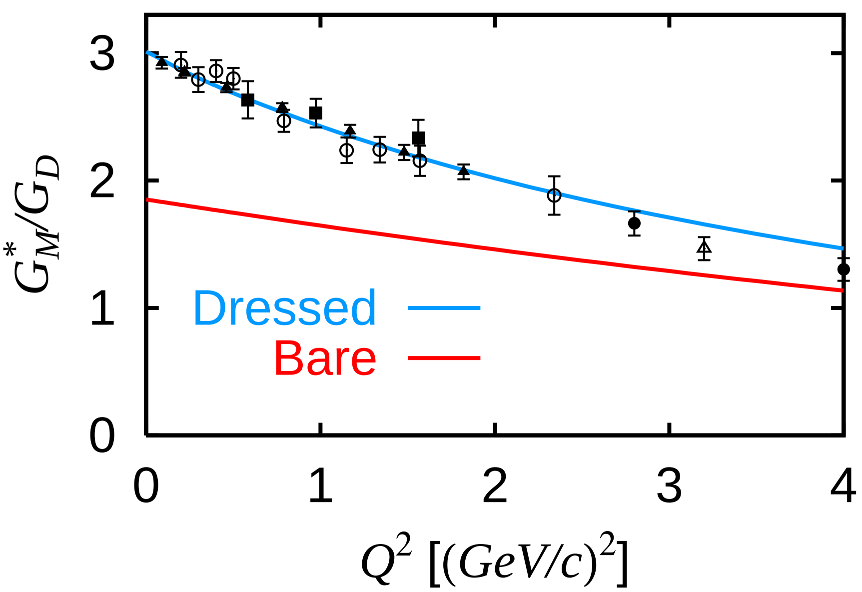
- Magnetic M1 A_M, A_M
  Electric E2 A_E, A_E
  Coulomb C2 A_C, A_C
- A_α compared with empirical amplitudes
- Naive Quark model $A_E = A_C = 0$

Magnetic Dipole

at $Q^2 = 0$

$$A_M = 271\ 10^{-3} GeV^{-1/2}$$

$$A_M = 173$$



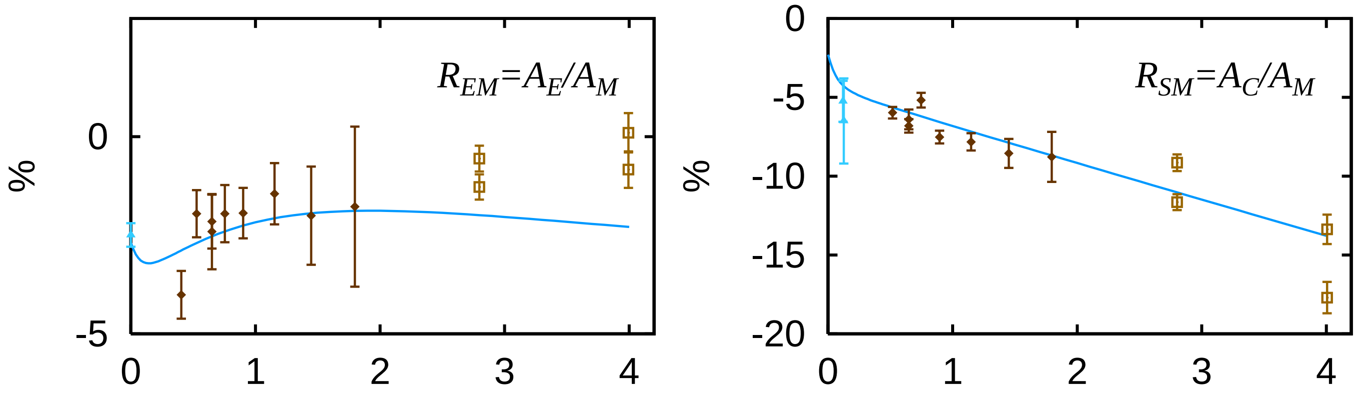
- $G_M^*(Q^2)$ drops faster than proton form factor
- Non-resonant process contributes about 40% at $Q^2 = 0$
- soft component of form factor due to meson cloud

Electric and Coulomb Quadrupole

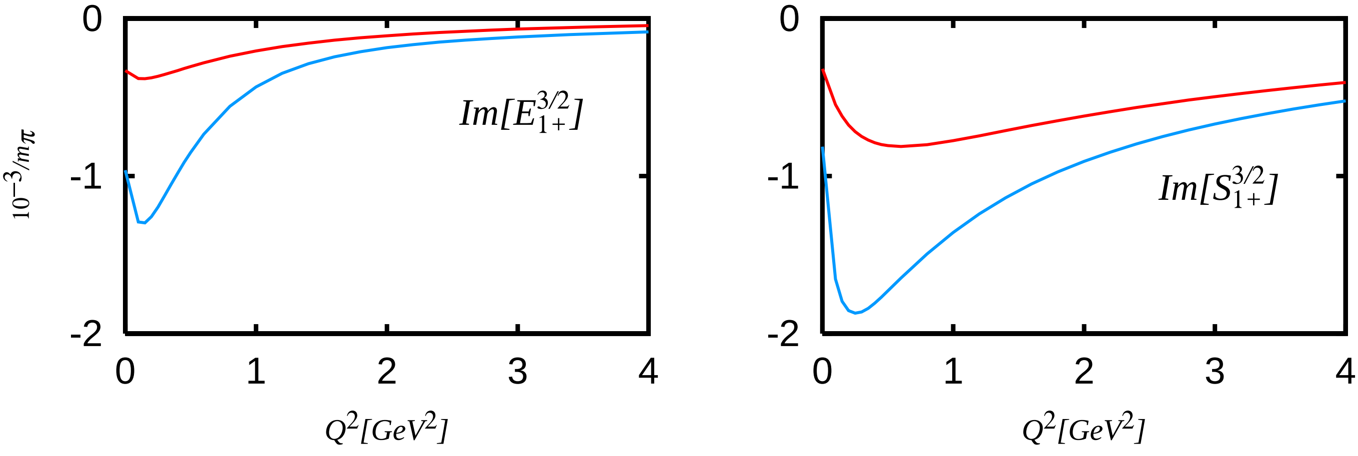
at $Q^2 = 0$

$A_E/A_M = -2.7$ % BRAG report -2.38 ± 0.27

$A_E/A_M = -1.3$



Data from DNP Town Meeting 2000



- E2,C2 components exist for both bare and dress
- Dressed R_{EM}, R_{SM} agree well with empirical amplitude analyses
- Low Q^2 enhancement due to pion cloud

DMT and MAID

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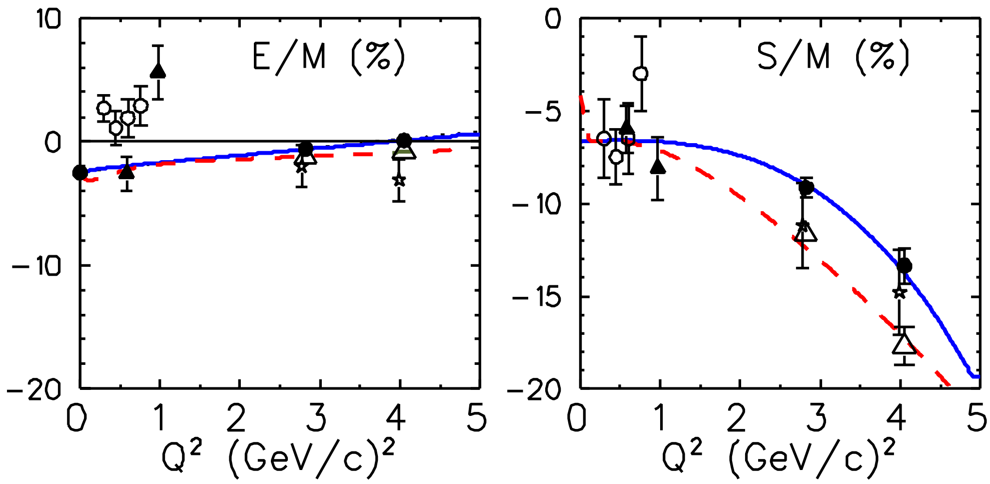
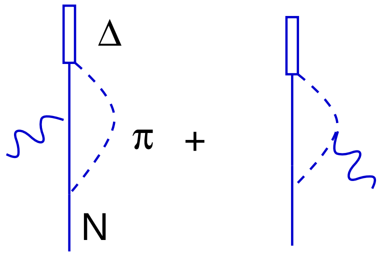


Role of Pion on $\gamma N \to \Delta$ Quadrupole (C2) Form Factor

Within SL model(Unitary transformation method)

- 'real' pion

$$A_C^{resc} = \int \Gamma_{\pi N \to \Delta} G_0 v_{\gamma\pi} =$$

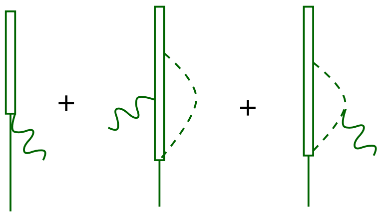


- 'virtual' pion

$$|B> = \frac{1}{\sqrt{Z_B}}[|qqq> + C|qqq\pi> + ...]$$

$\to$ renormalize $\gamma N \to \Delta$ vertex

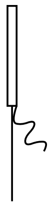
$$A_C^{Bare} =$$



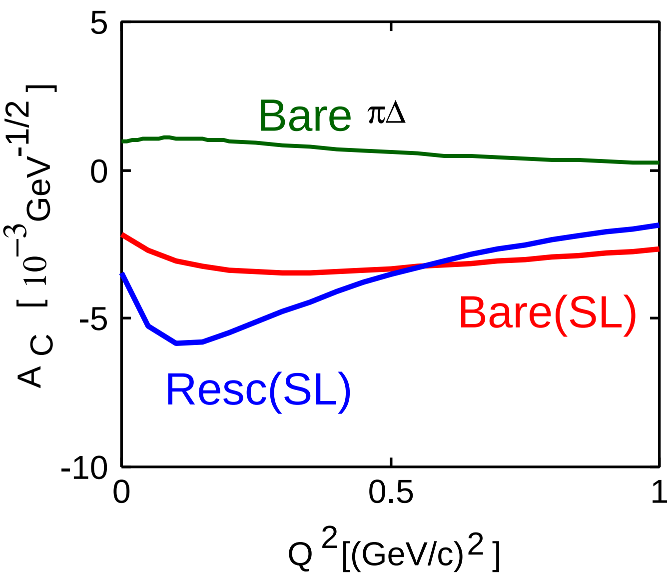
$\sim$ Chiral Bag Model
(Lu et al., Bermuth et al., Dong et al.)

Estimation using chiral constituent quark model

$(0s)^3$ configuration



$= 0$ $\qquad\qquad f_{\pi NN} \to f_{\pi N\Delta}, f_{\pi\Delta\Delta}$



- $A_C(\pi\Delta - loop)$ does not explain $A_C^{Bare}(SL)$

  Limit $m_\Delta \to m_N$

$$A_C(\pi\Delta - loop) = -A_C(\pi N - loop)$$

- Low Q^2 enhancement of S_{1+} is due to 'real' pion process

Summary

- The dynamical approach can describe extensive data of $\gamma N \to \pi N$ and $N(e, e'\pi)$ in the Δ region
- Can be used to test predictions of baryon resonances from hadron models
- Extracted $\gamma N \to \Delta$ form factors:
  - M1 form factor $G^*_M(Q^2)$ drops faster than proton form factor
  - Dressed $E2/M1$ and $C2/M1$ ratios agree well with empirical amplitude analyses
  - "dynamical" pion cloud has about 50% effect on the form factors at $Q^2 = 0$ and decreases as Q^2 increases
  - "static" $\pi - \Delta$ loop contribution to bare $E2$ and $C2$ disagree with extracted values
- Beyond Δ: Three-body treatment of $\pi\pi N$ channels must be developed

  A necessary step for a investigation of higher mass N^*