The $\gamma^{(*)}+p \to \Delta(1600)3/2+$ electromagnetic transition

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Outline

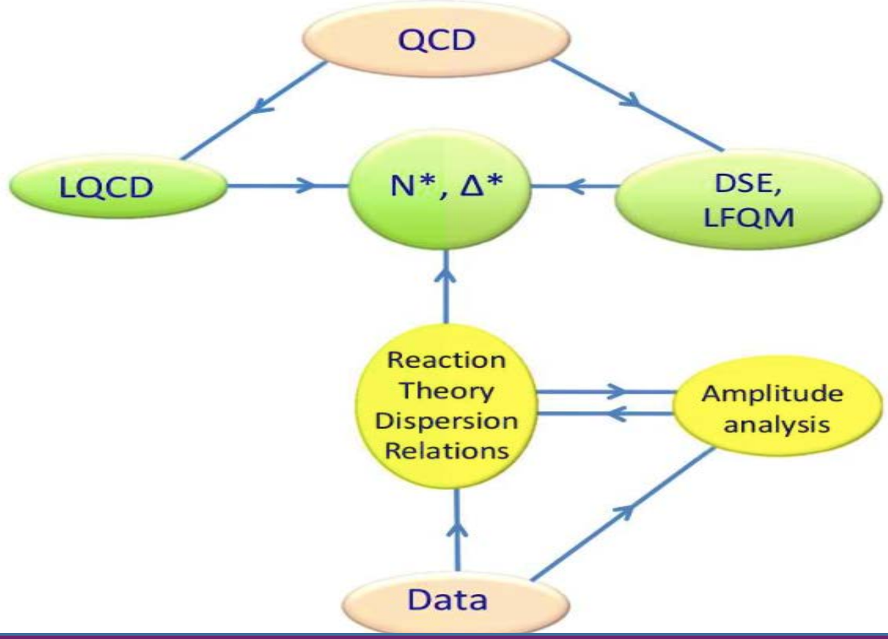
- **Background**
- **Method and Results**
- **Summary**

An understanding of the spectrum and internal structure of the excited nucleons ($N*$) remains to be a fundamental challenge in the hadron physics. Since the late 90s, huge amount of high precision data of meson photo- and electro-production reactions off a proton target has been reported from electron/photon beam facilities.

JLab, MAMI, ELSA, GRAAL, ...

They can be measured NOW with high precision!

Opens a great opportunity to make *quantitative* study of the N* states !!



- Determine N* spectrum
- Extract N* form factors
- Provide reaction mechanism information necessary for interpreting N* spectrum, structures and dynamical origins

Background:

A central goal of Nuclear Physics: understand the properties of hadrons in terms of the elementary excitations in Quantum Chromodynamics (QCD): quarks and gluons.

Elastic and transition form factors of N^*

Unique window into their quark and gluon structure

Broad range of photon virtuality Q^2

Unique information on the roles played by emergent phenomena in QCD

Probe the excited nucleon structures at perturbative and non-perturbative QCD scales

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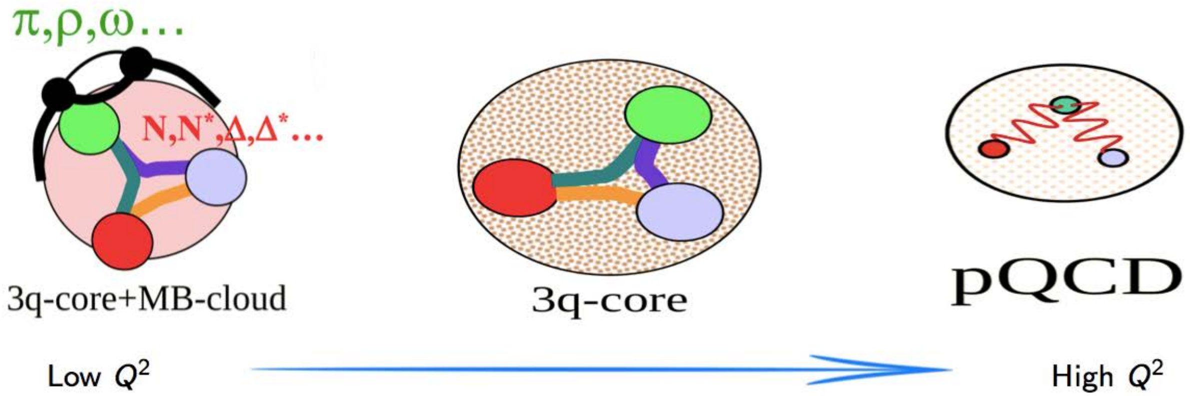
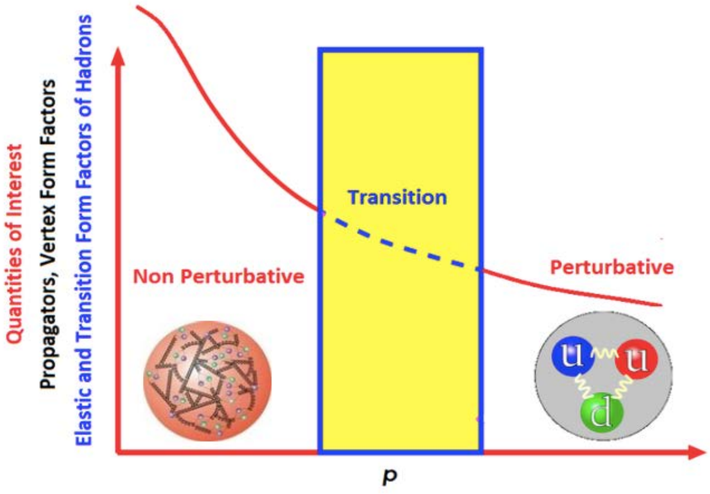
Parameterization formalism:

We employ a continuum quantum field theoretical approach based on the Dyson-Schwinger equations of Quantum Chromodynamics.





- **Large momenta are needed**
- **timelike and/or complex singularities that appear in propagator-----pole-free model**

Dressed-Quark Propagator :

$$S(p) = -i\gamma \cdot p\, \sigma_V(p^2) + \sigma_S(p^2)$$

$$\bar{\sigma}_S(x) = 2\bar{m}\,\mathcal{F}(2(x+\bar{m}^2)) + \mathcal{F}(b_1 x)\,\mathcal{F}(b_3 x)\,\left[b_0 + b_2\mathcal{F}(\epsilon x)\right],$$

$$\bar{\sigma}_V(x) = \frac{1}{x+\bar{m}^2}\left[1 - \mathcal{F}\left(2\left(x+\bar{m}^2\right)\right)\right],$$

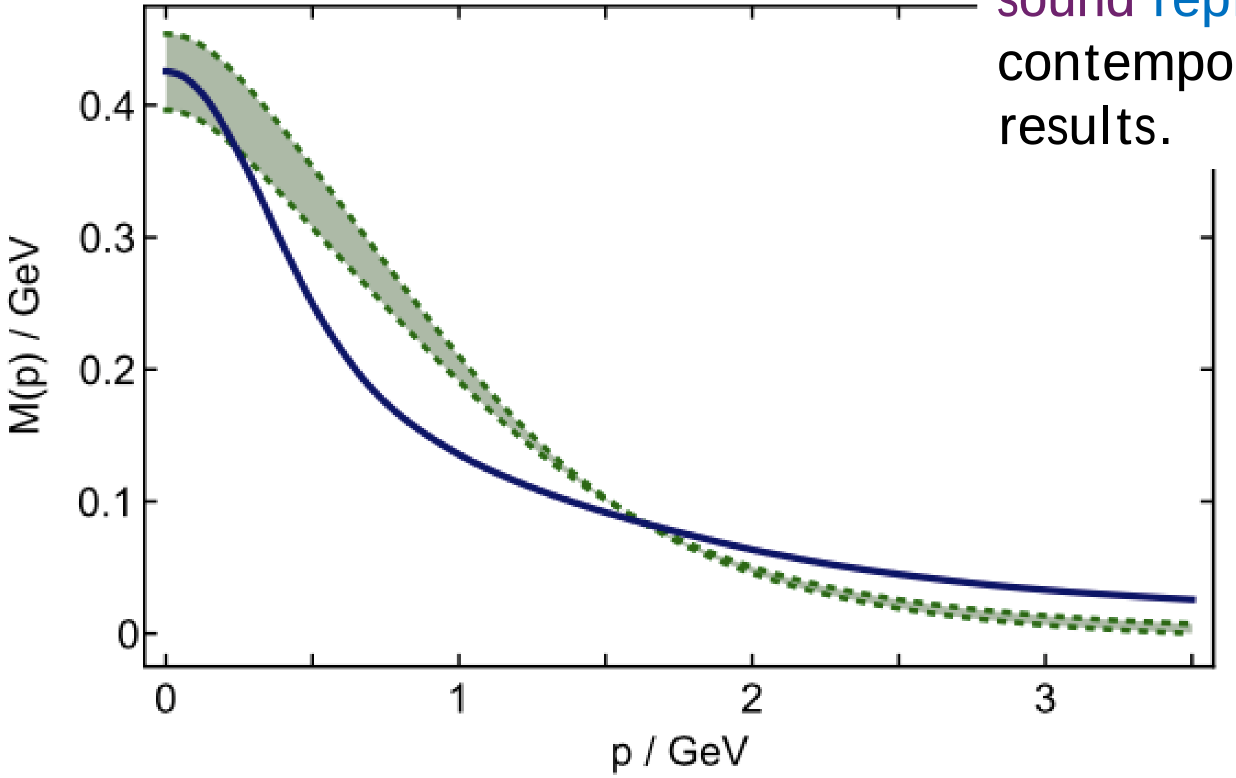
with $x = p^2/\lambda^2$, $\bar{m} = m/\lambda$, $\quad \mathcal{F}(x) = \frac{1-e^{-x}}{x}$

$\bar{\sigma}_S(x) = \lambda\,\sigma_S(p^2)$ and $\bar{\sigma}_V(x) = \lambda^2\,\sigma_V(p^2)$

$\lambda = 0.566\,\text{GeV}$,

$\bar{m}$	b_0	b_1	b_2	b_3
0.00897	0.131	2.90	0.603	0.185

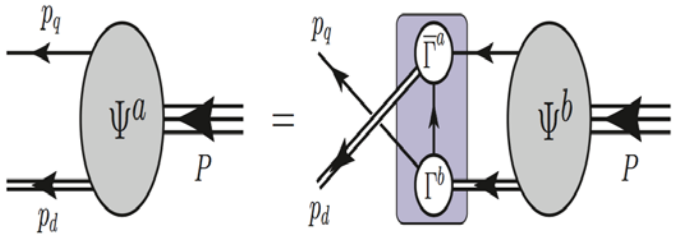
The parametrization is a sound representation of contemporary numerical results.



- Solid curve (blue): the parametrization of the dressed-quark propagator
- band (green):—modern DCSB-improved kernels results

Faddeev Equation:

The attractive nature of quark-antiquark correlations in a colour-singlet meson is also attractive for color-antitriplet diquark correlations within a baryon



- Our diquarks are not static
- nonpointlike and fully interacting
- Each quark participate

Positive parity states

↙ pseudoscalar and vector diquarks ↓ Ignored, wrong parity, larger mass-scales

↘ scalar and axial-vector diquarks ↓ Dominant, right parity, shorter mass-scales → N, R ⇒ 0^+, 1^+ diquarks; Δ ⇒ only 1^+ diquark

The mass of the ground state and its first excitation with quantum numbers $IJ^P = \frac{1}{2}\frac{1}{2}^+$ and $IJ^P = \frac{3}{2}\frac{3}{2}^+$ are (in GeV):

Calculation:

M_N =1.18, M_Δ =1.33,

$M_{N'}$=1.73, $M_{\Delta'}$=1.77.

Experimental:

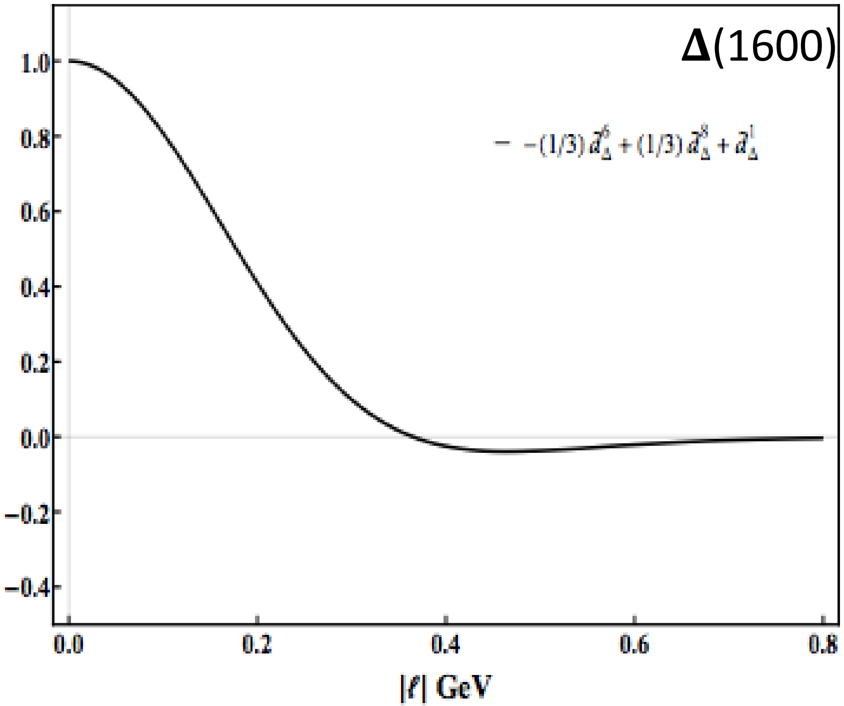
M_N =0.94, M_Δ =1.23,

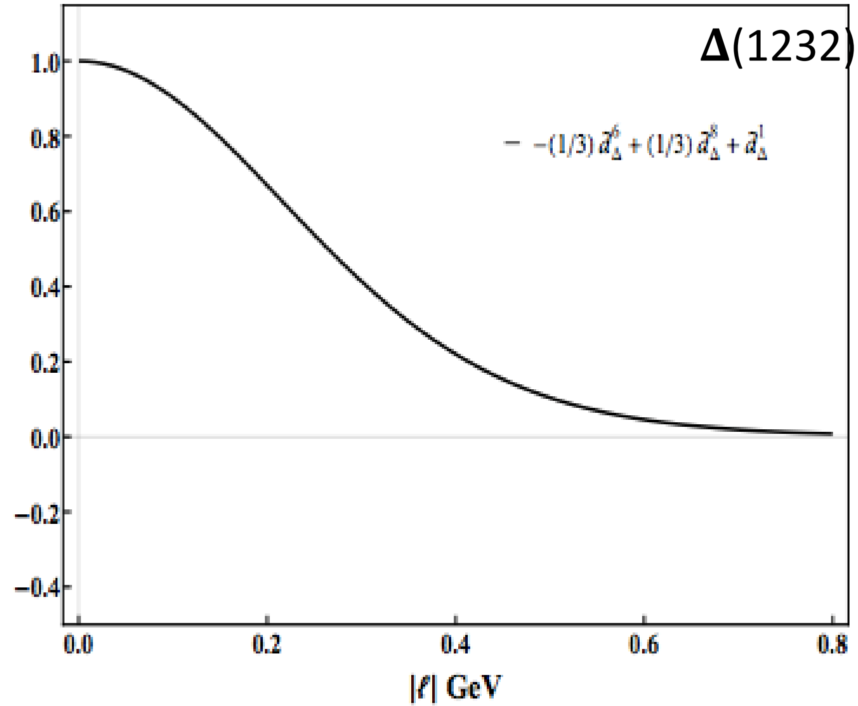
$M_{N'}$=1.44, $M_{\Delta'}$=1.60.

	$N_{940}^{P_{11}}$	$N_{1440}^{P_{11}}$	$N_{1535}^{S_{11}}$	$N_{1650}^{S_{11}}$	$\Delta_{1232}^{P_{33}}$
Herein	1.18	1.73	1.83	---	1.33
M_B^0 [69]		1.76	1.80	1.88	1.39

M_B^0:dynamical coupled-channels fitted bare masses.

The zeroth Chebyshev moment of S-wave Faddeev wave functions





- Delta 1232 is positive at the whole range
- Delta 1600 exhibits a single zero at momentum~0.4 GeV.
  ------be interpreted as a radial excitation

Difference between the first excitation of nucleon and Delta:

	$N(940)$	$N(1440)$	$\Delta(1232)$	$\Delta(1600)$
S-wave	0.76	0.85	0.61	0.30
P-wave	0.23	0.14	0.22	0.15
D-wave	0.01	0.01	0.17	0.52
F-wave	–	–	~ 0	0.02
scalar	62%	62%	–	–
pseudovector	29%	29%	100%	100%
mixed	9%	9%	–	–

- N(1440) has an orbital angular momentum composition which is very similar to the one observed in the nucleon.
- Roper's diquark content are almost identical to the nucleon's one.

But…

- ❑ Delta(1600) shows a dominant l= 2 angular momentum component
- ❑ its S-wave term being a factor 2 smaller than the one of the (1232).

☞ The electromagnetic current can be generally written as

$$J_{\mu\lambda}(K,Q) = \Lambda_+(P_f) R_{\lambda\alpha}(P_f) i\gamma_5 \Gamma_{\alpha\mu}(K,Q) \Lambda_+(P_i)$$

- P_i and P_f : the incoming nucleon and outgoing Delta momenta
  $${P_i}^2 = -{M_N}^2 \qquad {P_f}^2 = -{M_\Delta}^2$$
- Λ_+ : the positive energy projector for nucleon and Delta
- photon momentum Q=P_f-P_i
- The average momentum K=(P_i+P_f)/2

☞ Vertex decomposes in terms of three form factors:

$$\Gamma_{\alpha\mu}(K,Q) = \kappa\left[\frac{i\omega}{2\lambda_+}(G_M^* - G_E^*)\gamma_5\varepsilon_{\alpha\mu\gamma\delta}\check{K}_\gamma^\perp\check{Q}_\delta - G_E^*\mathcal{T}_{\alpha\gamma}^Q\mathcal{T}_{\gamma\mu}^K - \frac{i\tau}{\omega}G_C^*\check{Q}_\alpha\check{K}_\mu^\perp\right]$$

G_M, G_E and G_C are, respectively, the magnetic dipole, electric quadrupole and Coulomb (longitudinal) quadrupole form factors

$$\check{K}_\mu^\perp = \mathcal{T}_{\mu\nu}^Q\check{K}_\nu = (\delta_{\mu\nu} - \check{Q}_\mu\check{Q}_\nu)\check{K}_\nu$$

$$\kappa = \sqrt{\frac{3}{2}}\left(1 + \frac{m_\Delta}{m_N}\right),$$

$$\omega = \sqrt{\lambda_+\lambda_-},$$

$$\lambda_\pm = \frac{(m_\Delta \pm m_N)^2 + Q^2}{2(m_\Delta^2 + m_N^2)},$$

$$\tau = \frac{Q^2}{2(m_\Delta^2 + m_N^2)};$$

☞ Form factors can be obtained by any sensible projection operators. These form factors are the exlusive functions of the four-momentum transfer squared, Q2, and frame independent.

Scalars function:

$$t_1 = \mathcal{T}^{\check{K}^\perp}_{\mu\nu}\, \check{K}^\perp_\lambda\, \mathrm{tr}[\gamma_5 J_{\mu\lambda}\gamma_\nu]\,,$$
$$t_2 = \mathcal{T}^{\check{K}^\perp}_{\mu\lambda}\, \mathrm{tr}[\gamma_5 J_{\mu\lambda}]\,,$$
$$t_3 = \check{K}^\perp_\mu\, \check{K}^\perp_\lambda\, \mathrm{tr}[\gamma_5 J_{\mu\lambda}]\,,$$

$$G_M^* = \frac{3\sqrt{1-4\delta^2}}{4i\kappa\omega}\left[\frac{\lambda_+}{\omega}t_2 + \frac{\sqrt{\tau}\sqrt{1+2\delta}}{\delta-\tau}t_1\right],$$
$$G_E^* = \frac{\sqrt{1-4\delta^2}}{4i\kappa\omega}\left[\frac{\lambda_+}{\omega}t_2 - \frac{\sqrt{\tau}\sqrt{1+2\delta}}{\delta-\tau}t_1\right],$$
$$G_C^* = \frac{3\sqrt{1-4\delta^2}}{4i\kappa\omega^2}\frac{\lambda_+(1+2\delta)}{\delta-\tau}t_3\,.$$

where

$$\delta = \frac{m_\Delta^2 - m_N^2}{4\xi^2}\,, \quad \text{and} \quad \xi^2 = \frac{m_\Delta^2 + m_N^2}{2}\,.$$

Two ratios:

$$R_{EM} = -\frac{G_E^*}{G_M^*}\,,$$
$$R_{SM} = -\frac{|\vec{Q}|}{2m_\Delta}\frac{G_C^*}{G_M^*} = -\frac{\omega}{1+2\delta}\frac{G_C^*}{G_M^*}\,,$$

measures of deformation of the hadrons involved.

Microscopic computation of the electro-magnetic current :

One must specify how the photon couples to the constituents within the baryon.

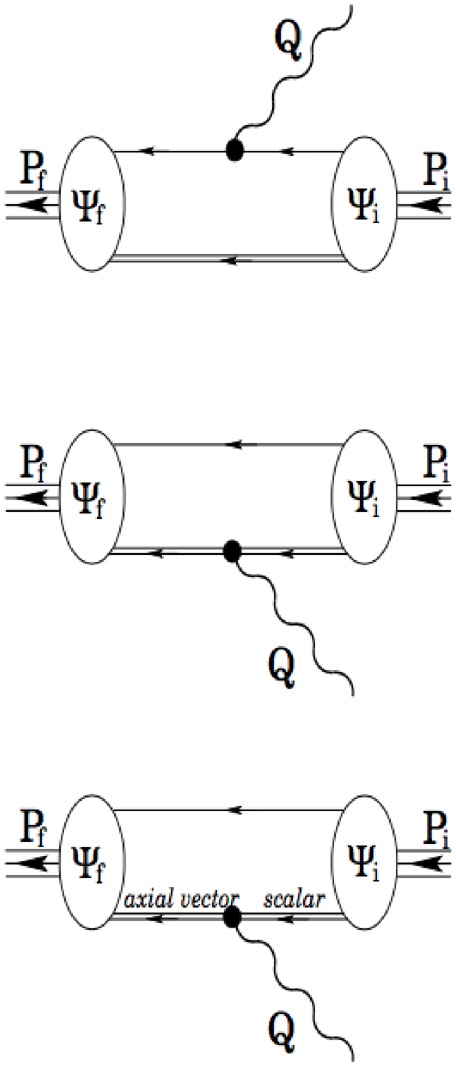
$\Downarrow$

Six contributions to the current in the quark-diquark picture

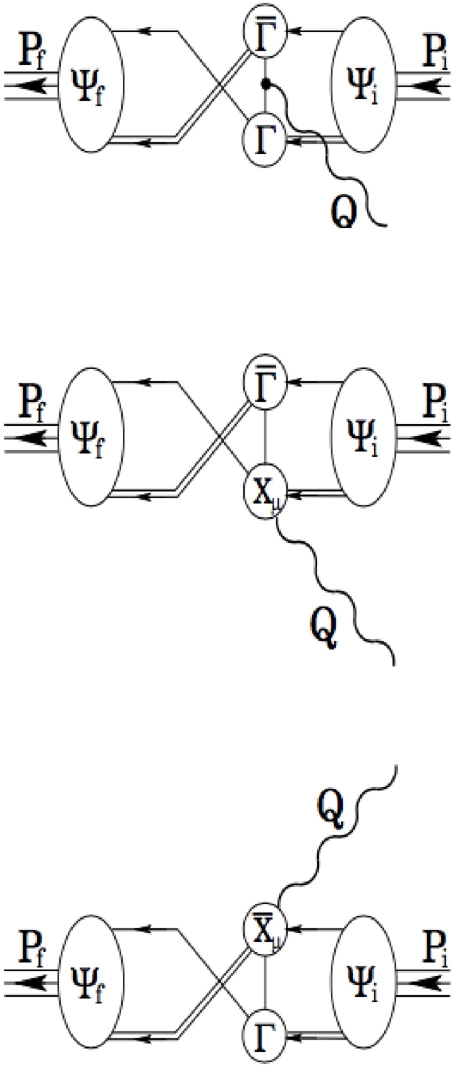
$\Downarrow$

1. *Coupling of the photon to the dressed quark.*
2. *Coupling of the photon to the dressed diquark:*
   - *Elastic transition.*
   - *Induced transition.*
3. *Exchange and seagull terms.*

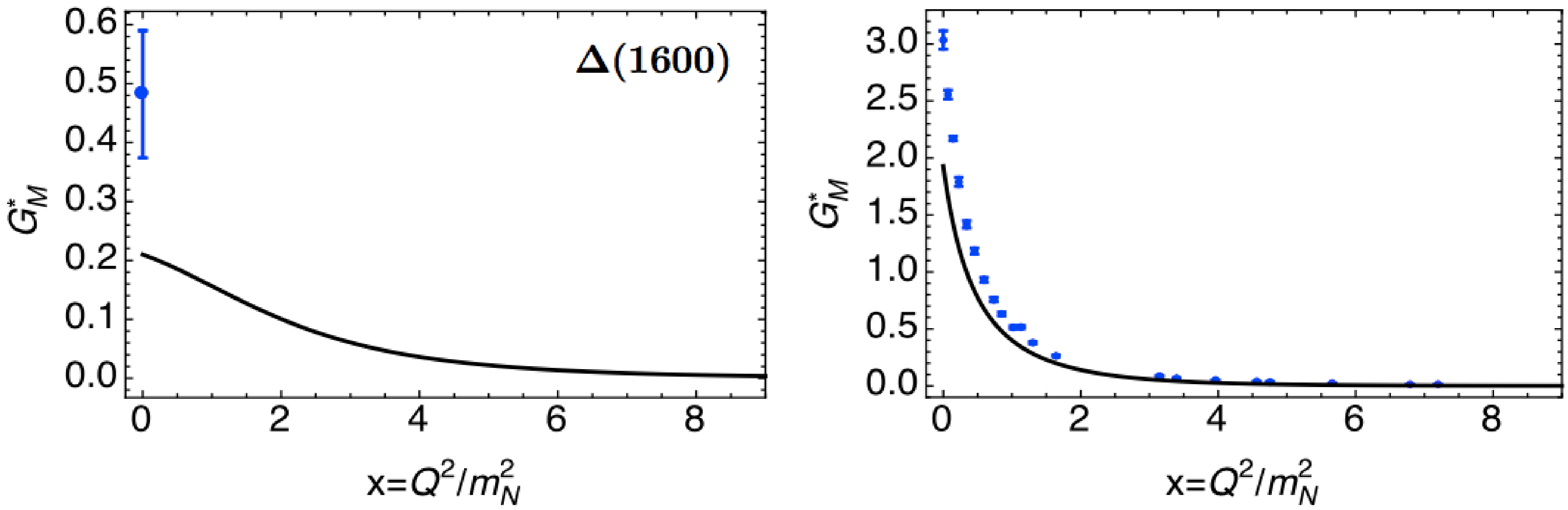
One-loop diagrams



Two-loop diagrams



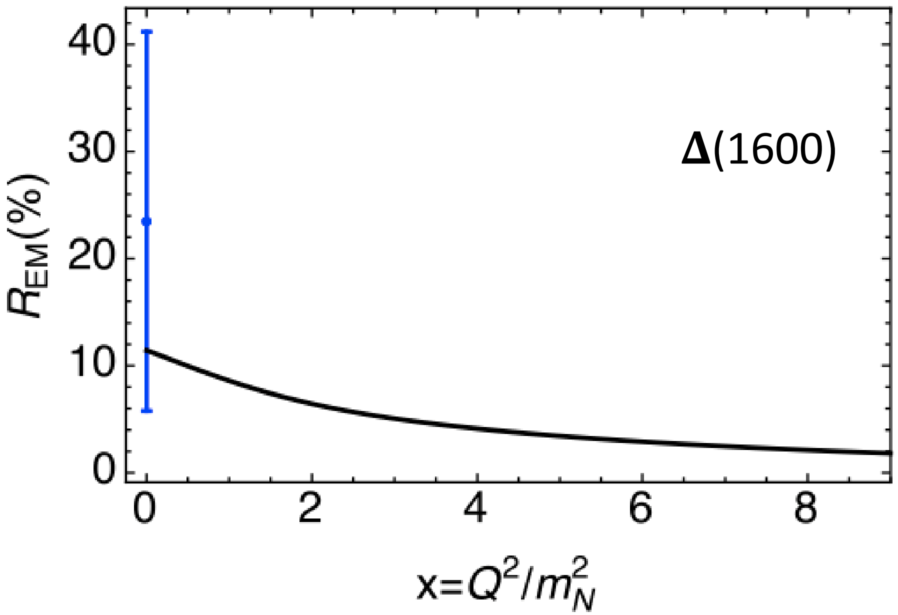
Q^2 -evolution of the magnetic dipole form factor:

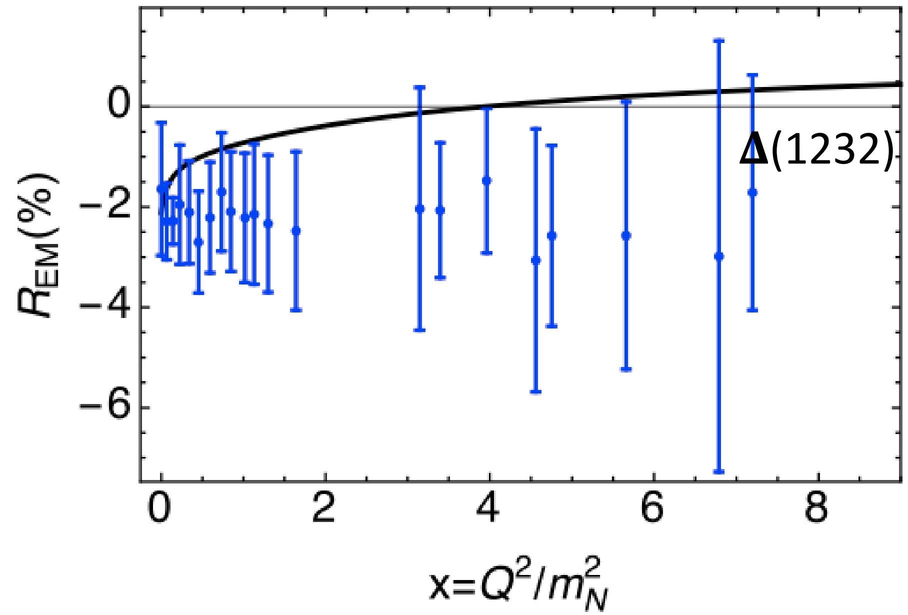


- spin flip : G_M dominant
  - decreases smoothly from 0.21
  - Experimentally is roughly twice of our results.

  ……..
- G_E, G_C measure the deformation

Electric ratio



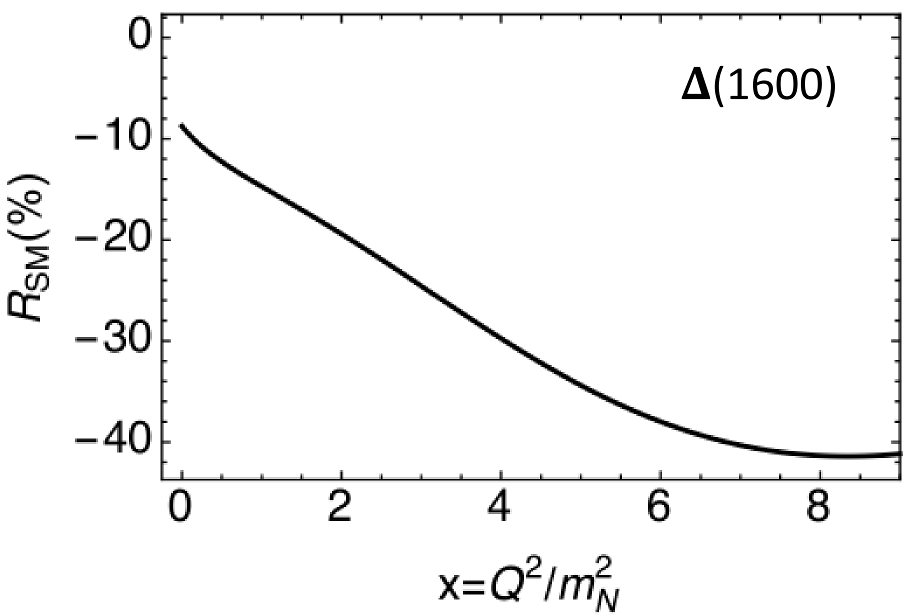


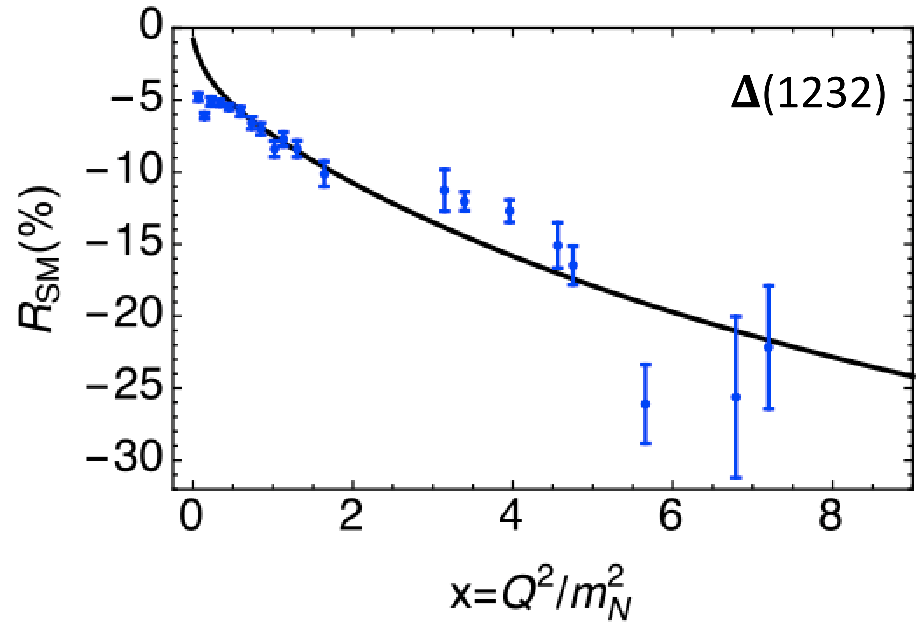
Both reaction ratios are compatible with the experimental data. Because meson cloud effects cancel in the ratio. Thus this ratio is a particularly sensitive measure of orbital angular momentum correlations.

$$|R^{\Delta'}_{EM}| \sim 5R^{\Delta}_{EM}$$

Δ1600 orbital angular momentum components higher than **Δ**(1232) decuplet baryon

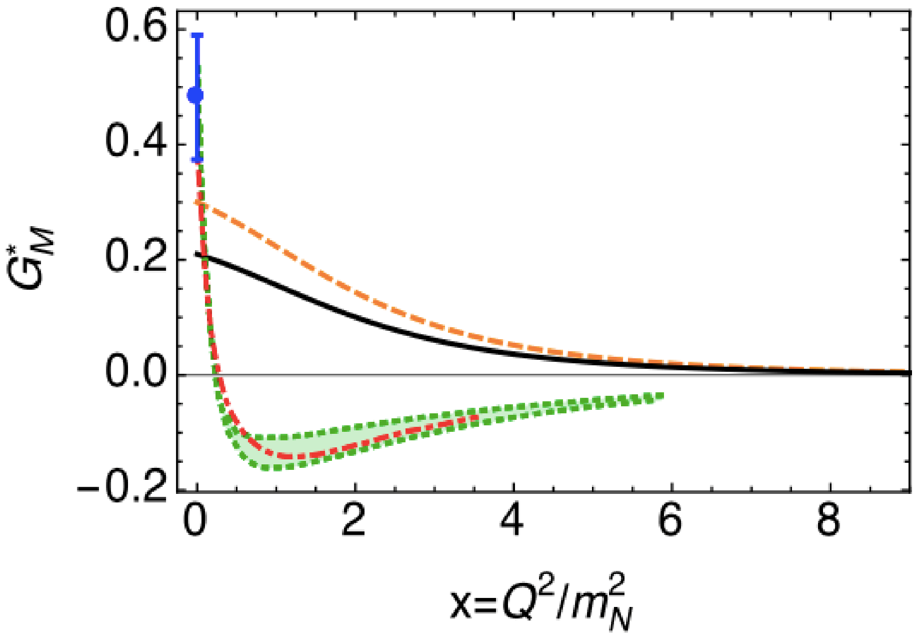
Coulomb ratio





$$R_{SM}^{\Delta'} \gtrsim R_{SM}^{\Delta}$$

indicating that more higher orbital angular momentum components in the **Δ**(1600)

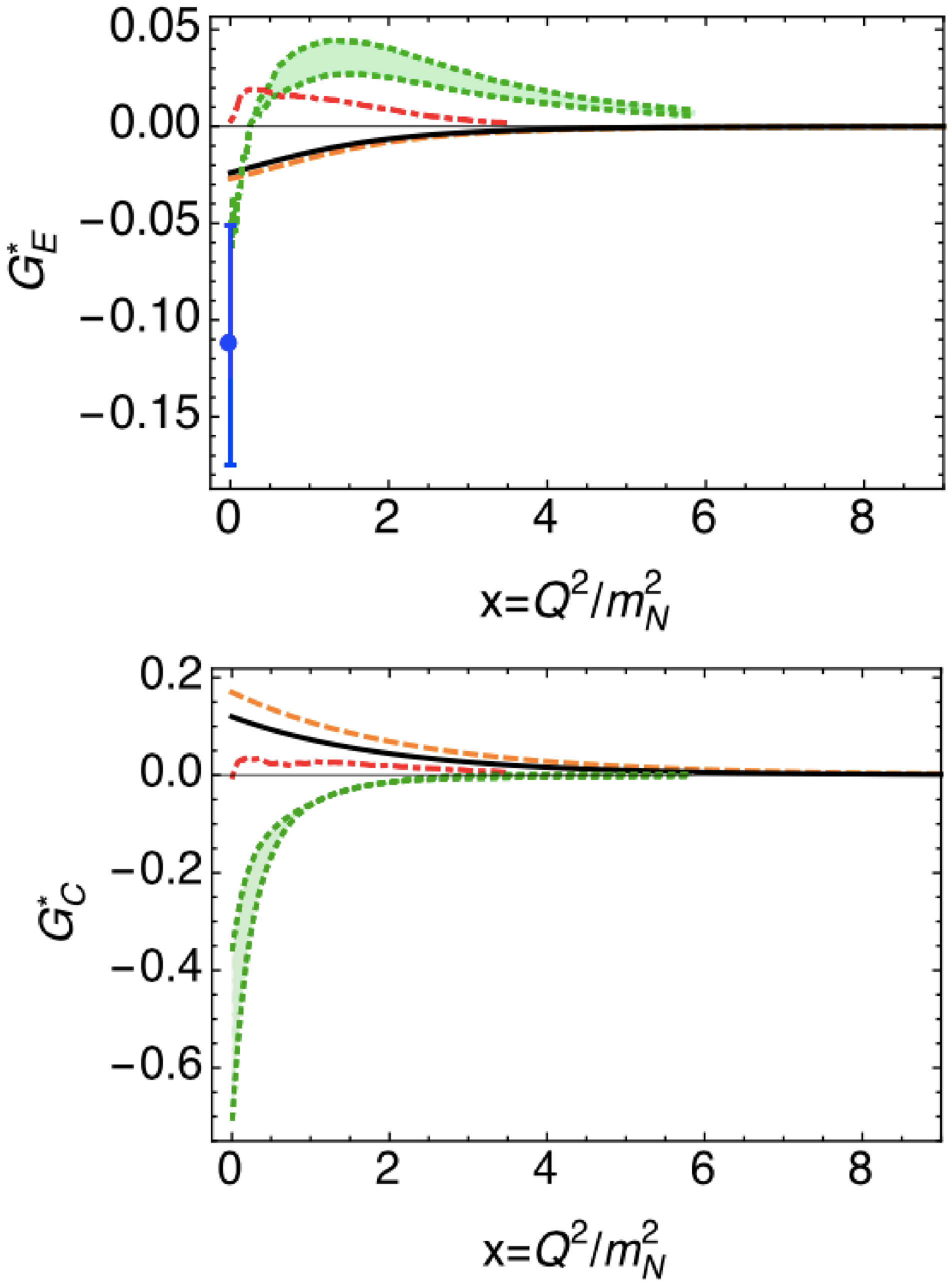


- **The blue points:**
  extracted from the photo-couplings
- **greed-dashed lines:**
  light-front relativistic quark model
- **red–dot-dashed line:**
  light-front relativistic Hamiltonian
- **Black solid line:**
  Our calculation
- **orange-dashed line:**
  artificially increase the meson cloud contribution

➢ Light-front methods:Q2 -evolution of G_M reflects the radial excitation character of $\mathbf{\Delta}(1600)$

➢ Indeed radial excitation: with the appearance of a zero crossing in the lowest Chebyshev moment of its S-wave component

➢ But this feature is obscured: the D-wave component contributes ~ 50% to the Delta(1600)'s composition and that the l = 1 term is comparable in size with that of the l= 0.



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Summary

- We present a computation of the form factors that characterize the $\gamma(*)+p \rightarrow \Delta(1600)3/2+$ reaction as a step towards an unified study of the electromagnetic transition properties associated with the nucleon and its resonances.

- The electric and Coulomb quadrupoles at the physical photon point, but also along the whole range of transferred momenta, are larger than in the case of the (1232)3/2+ reaction, indicating a larger presence of higher orbital angular momentum components in the (1600) than in the (1232).

- There are similarities between the (1600) and (1232) when studying the Q2-evolution of all form factors such as the need of meson-baryon final-state interactions (meson cloud) to explain part of their magnitude at low-Q2; and there is no zero crossing for the dominant magnetic dipole form factor because the presence of higher angular momentum components of the (1600), which is an inescapable consequence of solving a realistic Poincaŕe-covariant Faddeev equation, obscures its radial excitation character.

Thank You!