Valence quark contributions for the $\gamma N \to P_{11}(1440)$ transition

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In collaboration with Kazuo Tsushima

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Motivation and goals

- Understand of the electromagnetic structure of the resonance $P_{11}(1440) \equiv$ Roper $\simeq N^*$
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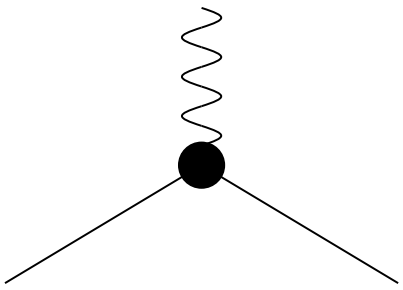
- $\Longrightarrow$ compare with CLAS data & MAID analysis
  $\Longrightarrow$ estimate meson cloud contribution

Spectator quark model –quark current

- Constituent quarks (quark form factors)

$$j_I^\mu = \left[\frac{1}{6}f_{1+} + \frac{1}{2}f_{1-}\tau_3\right]\left(\gamma^\mu - \frac{\not{q}q^\mu}{q^2}\right) + \left[\frac{1}{6}f_{2+} + \frac{1}{2}f_{2-}\tau_3\right]\frac{i\sigma^{\mu\nu}q_\nu}{2M_N}$$

Quarks with anomalous magnetic moments κ_u, κ_d



quark-antiquark

$\oplus$ gluon dressing

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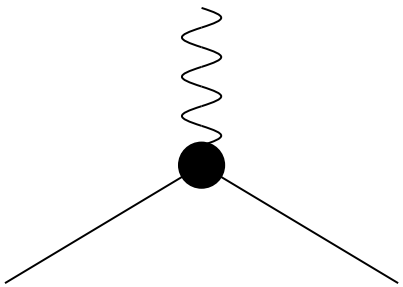

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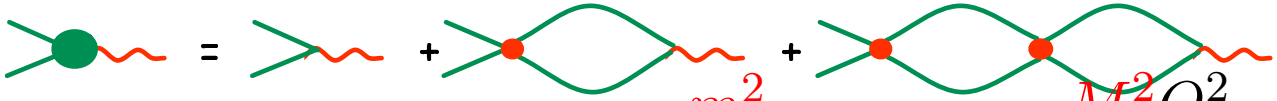
- Vector meson dominance parameterization:



$$f_{1\pm} = \lambda_q + (1-\lambda_q)\frac{m_v^2}{m_v^2+Q^2} + c_\pm \frac{M_h^2 Q^2}{(M_h^2+Q^2)^2}$$

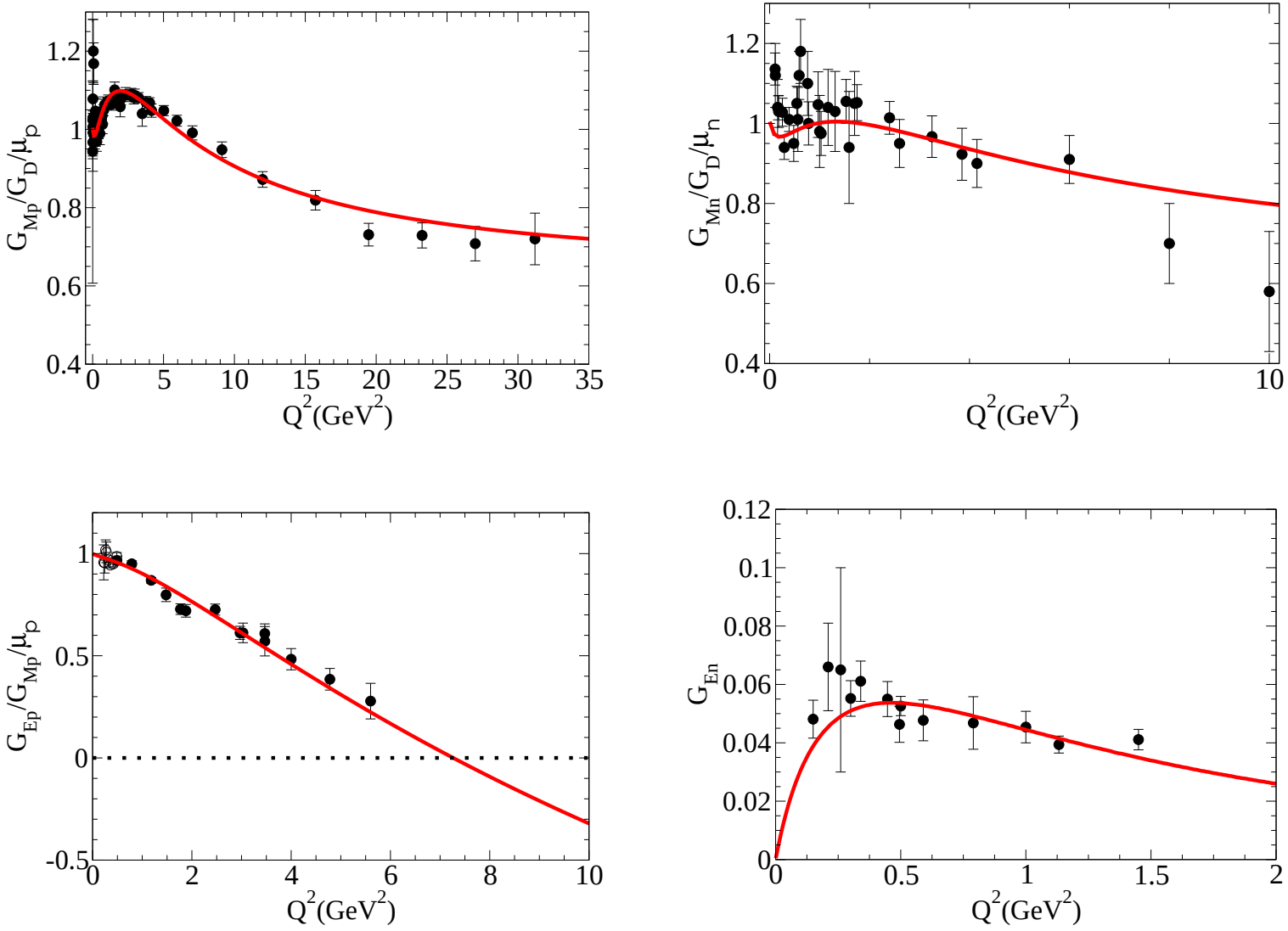
$$f_{2\pm} = \kappa_\pm \left\{ d_\pm \frac{m_v^2}{m_v^2+Q^2} + (1-d_\pm)\frac{M_h^2}{M_h^2+Q^2} \right\}$$

2 poles: $m_v = m_\rho$ and $M_h = 2M_N$; $\kappa_\pm \Leftarrow$ nucleon mag. mom.

5 parameters to be determined: λ_q,

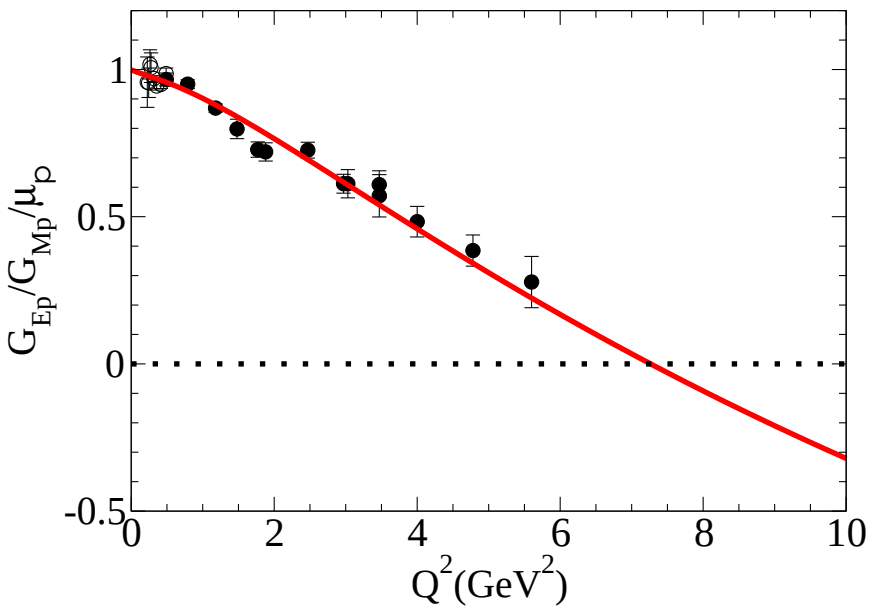
mixture coefficients $c_\pm$ and $d_\pm$ with $d_+ = d_-$ [4 parameters]

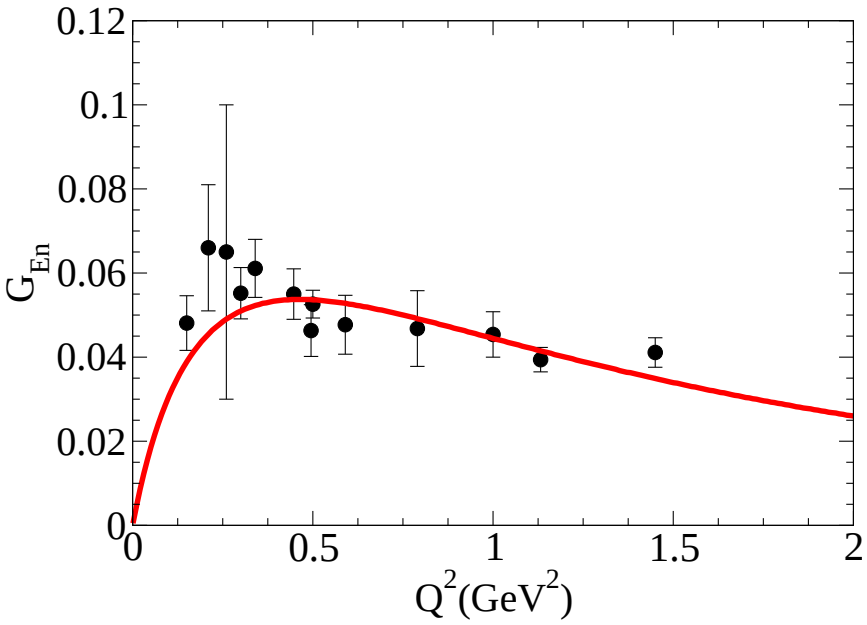
Results: Nucleon form factors (I)



Results: Nucleon form factors (II)

F Gross, GR and MT Peña, PRC 77, 015202 (2008) – model II





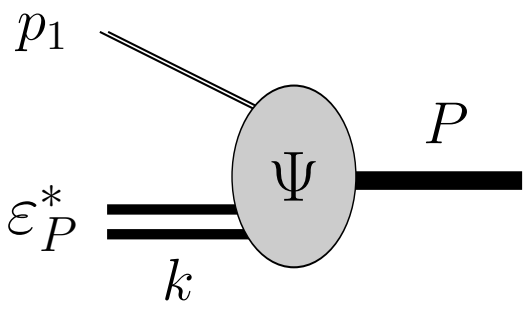
Quark current fixed [4 parameters]

No pion cloud (explicit) ... but VMD

Adjust 2 parameters in the nucleon wave function

Spectator quark model –Wave functions

- Wave functions: $B = \text{quark} \oplus \text{diquark}$



$$\Psi_B = \sum (\text{flavor}) \otimes (\text{spin}) \otimes (\text{orbital}) \otimes (\text{radial})$$

Nucleon wave function: [PRC 77,015202 (2008)]

Simplest structure –S-state in quark-diquark

$$\Psi_N(P,k) = \frac{1}{\sqrt{2}} \left[\Phi_I^0 \Phi_S^0 + \Phi_I^1 \Phi_S^1 \right] \psi_N(P,k)$$

Roper wave function:

$$\Psi_R(P,k) = \frac{1}{\sqrt{2}} \left[\Phi_I^0 \Phi_S^0 + \Phi_I^1 \Phi_S^1 \right] \psi_R(P,k)$$

ψ_R **first radial** excitation of ψ_N

$\Phi_I^{0,1}$ isospin; $\Phi_S^{0,1}$ spin – combination of **quark states**

$\Longrightarrow$ **written** in terms of **baryon** properties

$\Longrightarrow$ Covariant Ψ_B: $(\not{P} - M_N)\Psi_N = 0$, $(\not{P} - M_R)\Psi_R = 0$

Spectator quark model – Nucleon and Roper wf

Scalar wave functions deppendent of P (baryon) and k (diquark)

$$\chi_B = \frac{(M_B - m_D)^2 - (P-k)^2}{M_B m_D},$$

$M_B =$ baryon mass; $m_D =$ diquark mass

Momentum range parameters β_1 (long) and β_2 (short)

$$\begin{aligned}
\psi_N(P,k) &= N_0 \frac{1}{m_D(\beta_1+\chi_N)(\beta_2+\chi_N)} \\
\psi_R(P,k) &= N_R \frac{\beta_3 - \chi_R}{(\beta_1+\chi_R)} \frac{1}{m_D(\beta_1+\chi_R)(\beta_2+\chi_R)}
\end{aligned}$$

Harmonic oscilator potential- 1st order in χ_R

Nucleon orthogonal to Roper:

$$\int_k \psi_R(P_+,k)\psi_N(P_-,k)\Big|_{Q^2=0} = 0$$

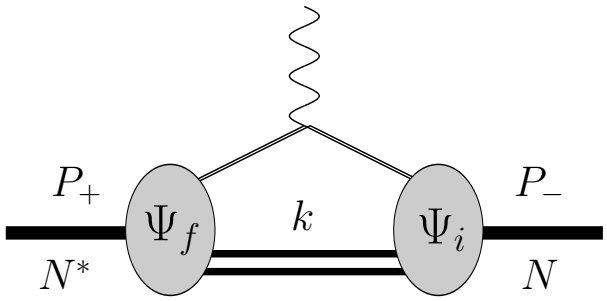
fix β_3
[no parameters]

Spectator quark model –Electromagnetic transition current

Quark current $j_I^\mu \bigoplus$ Baryon wave function $\Psi_B \Rightarrow J^\mu$

- Spectator formalism: relativistic inpulse approximation

$$J^\mu = 3 \sum_\lambda \int_k \bar{\Psi}_f(P_+, k) j_I^\mu \Psi_i(P_-, k)$$



diquark on-shell

Franz Gross: PR186, 1448 (1969);
F Gross er al PRC 45, 2094 (1992)

$$J^\mu = \bar{u}_R(P_+) \left\{ \left(\gamma^\mu - \frac{\not{q} q^\mu}{q^2} \right) F_1^*(Q^2) + \frac{i\sigma^{\mu\nu} q_\nu}{M_R + M} F_2^*(Q^2) \right\} u(P_-)$$

$\gamma N \to$ Roper form factors [PRD 81, 074020 (2010)]

$$
\begin{aligned}
F_1^*(Q^2) &= \frac{3}{2} j_1 \mathcal{I} + \frac{1}{2} \frac{3(M_R+M)^2 - Q^2}{(M_R+M)^2+Q^2} j_3 \mathcal{I} \\
&\quad - \frac{M_R+M}{M} \frac{Q^2}{(M_R+M)^2+Q^2} j_4 \mathcal{I}, \\
F_2^*(Q^2) &= \frac{3}{4} \frac{M_R+M}{M} j_2 \mathcal{I} - \frac{(M_R+M)^2}{(M_R+M)^2+Q^2} j_3 \mathcal{I} \\
&\quad + \frac{M_R+M}{2M} \frac{(M_R+M)^2 - 3Q^2}{(M_R+M)^2+Q^2} j_4 \mathcal{I},
\end{aligned}
$$

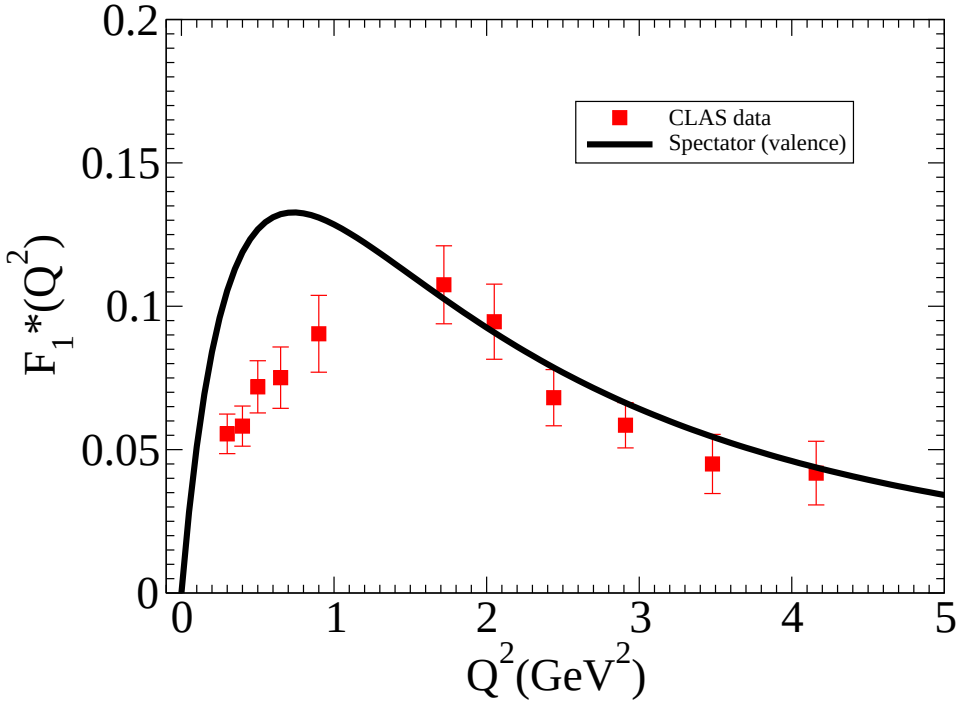
Isospin coefficients – GR, MTP, and FG, PRC 77, 015202 (2008)

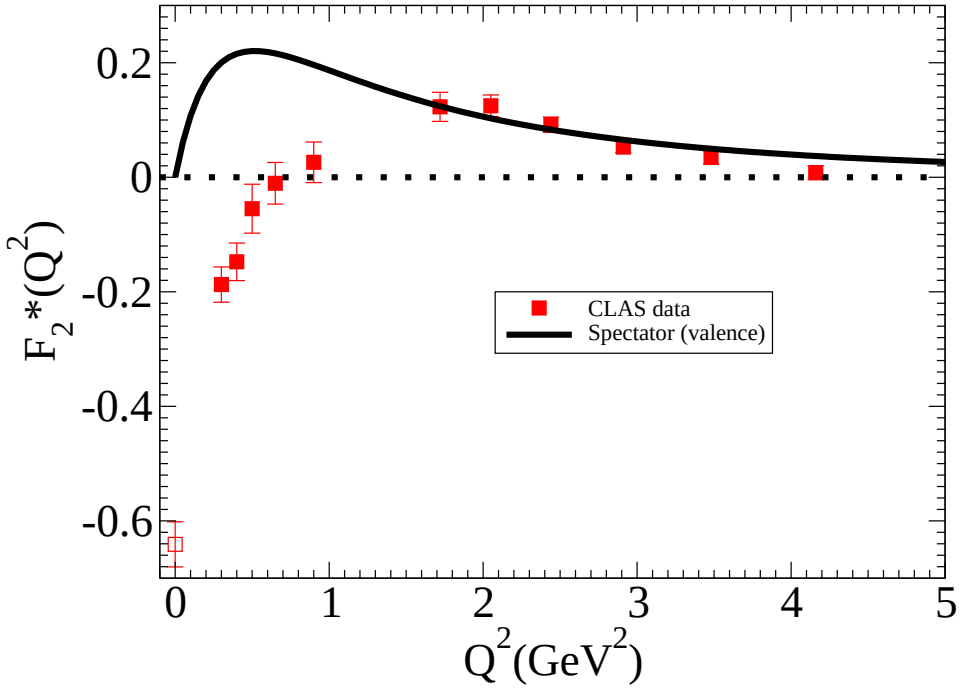
$$
\begin{aligned}
j_1 &= \tfrac{1}{6} f_{1+} + \tfrac{1}{2} f_{1-} \tau_3, \quad j_3 = \tfrac{1}{6} f_{1+} - \tfrac{1}{6} f_{1-} \tau_3 \\
j_2 &= \tfrac{1}{6} f_{2+} + \tfrac{1}{2} f_{2-} \tau_3, \quad j_4 = \tfrac{1}{6} f_{2+} - \tfrac{1}{6} f_{2-} \tau_3
\end{aligned}
$$

Overlap integral:

$$
\mathcal{I}(Q^2) = \int_k \psi_R(P_+, k) \psi_N(P_-, k),
$$

$\gamma N \longrightarrow$ Roper form factors- results





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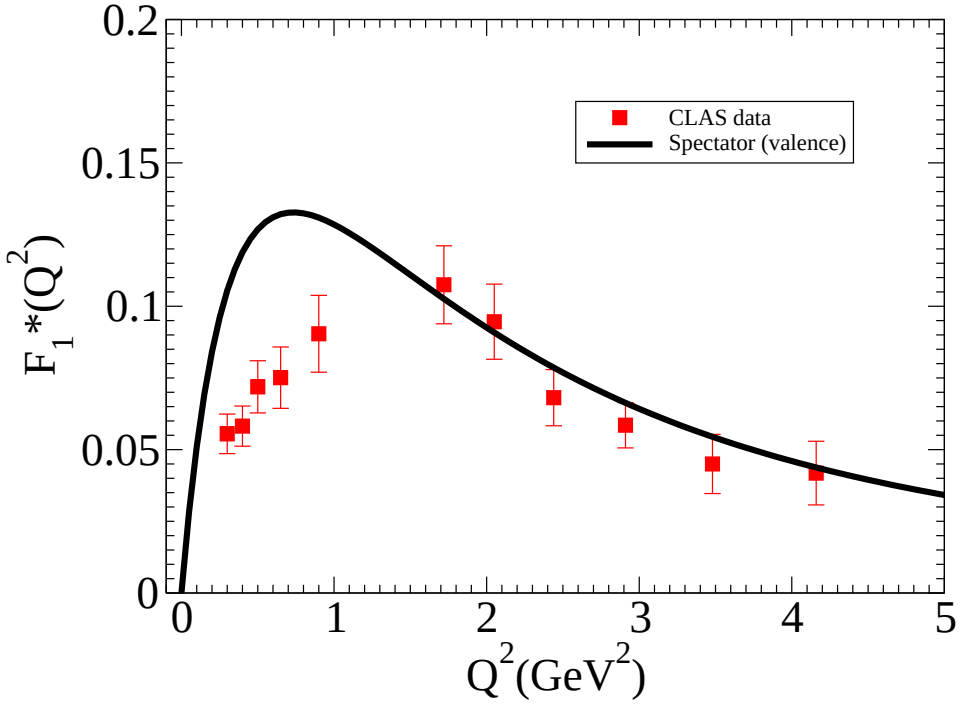

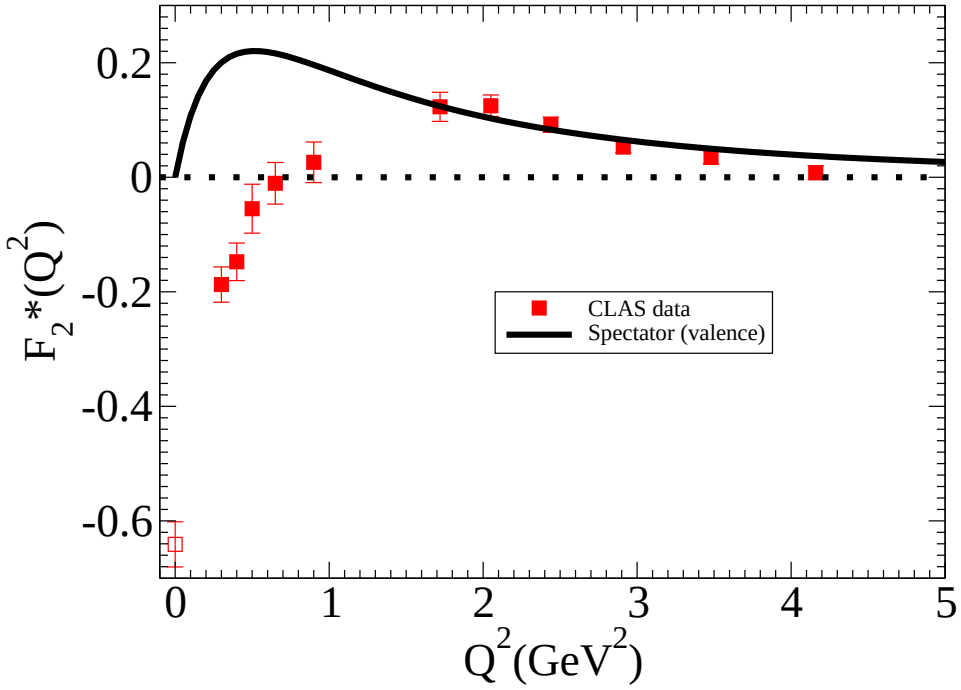

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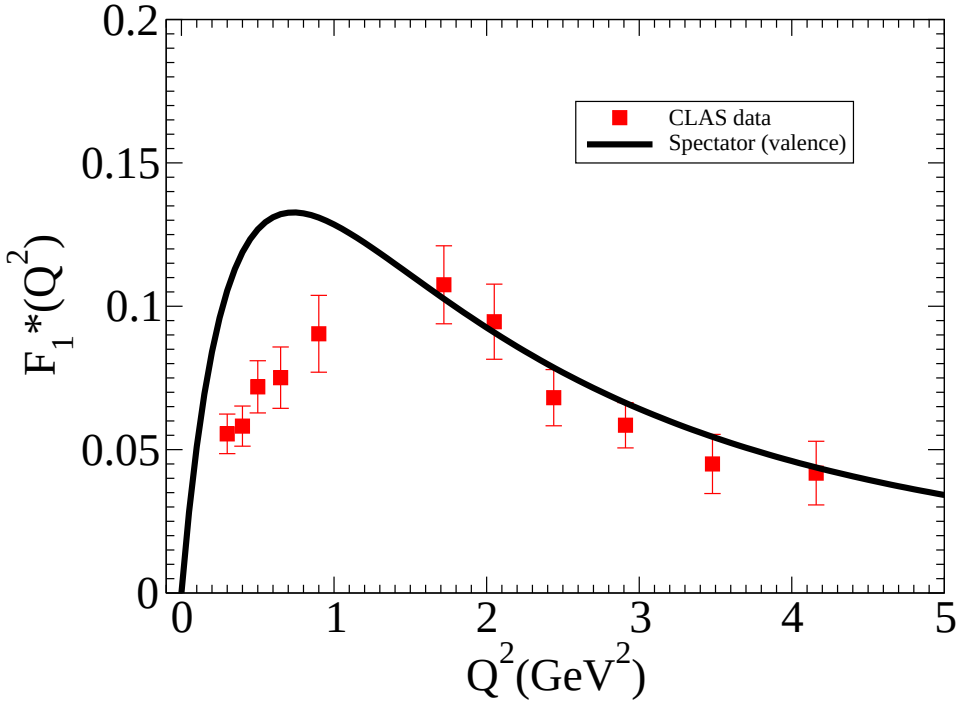

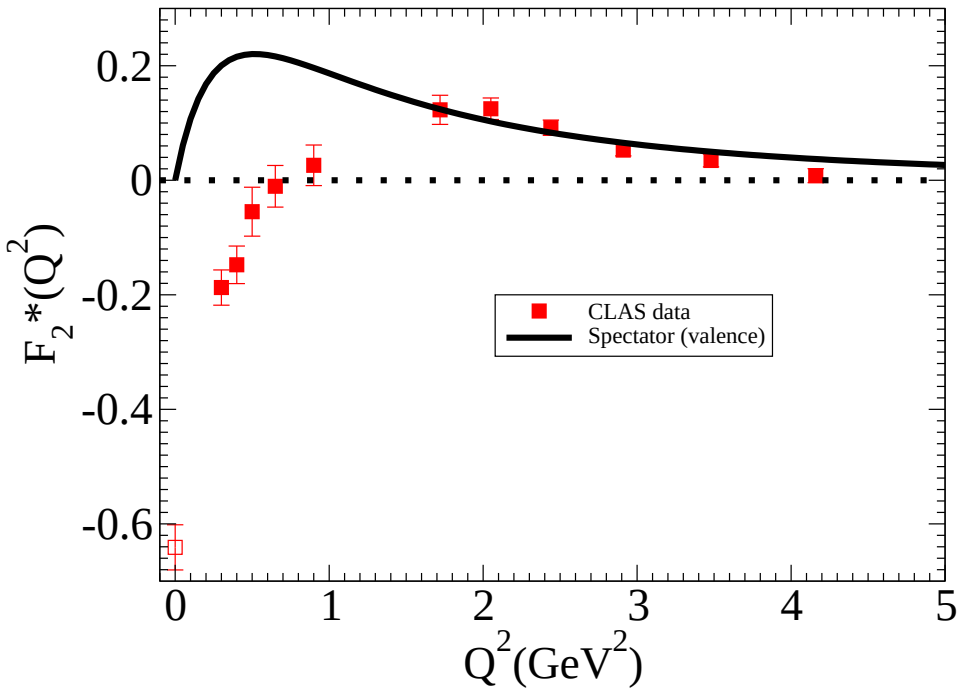

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- Good description for $Q^2 > 1.5$ GeV^2

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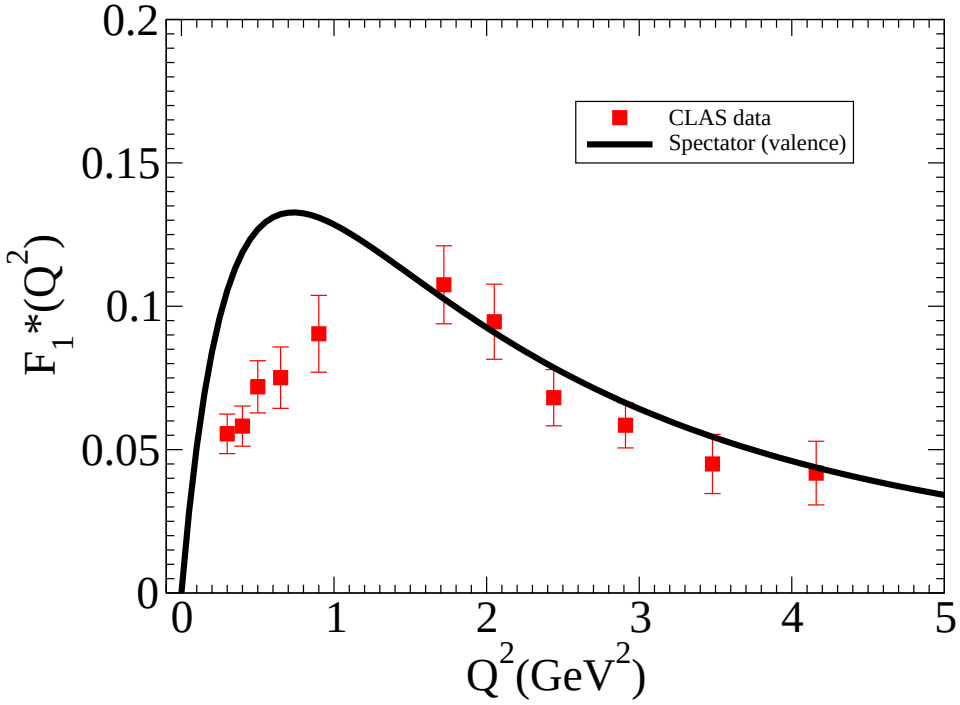

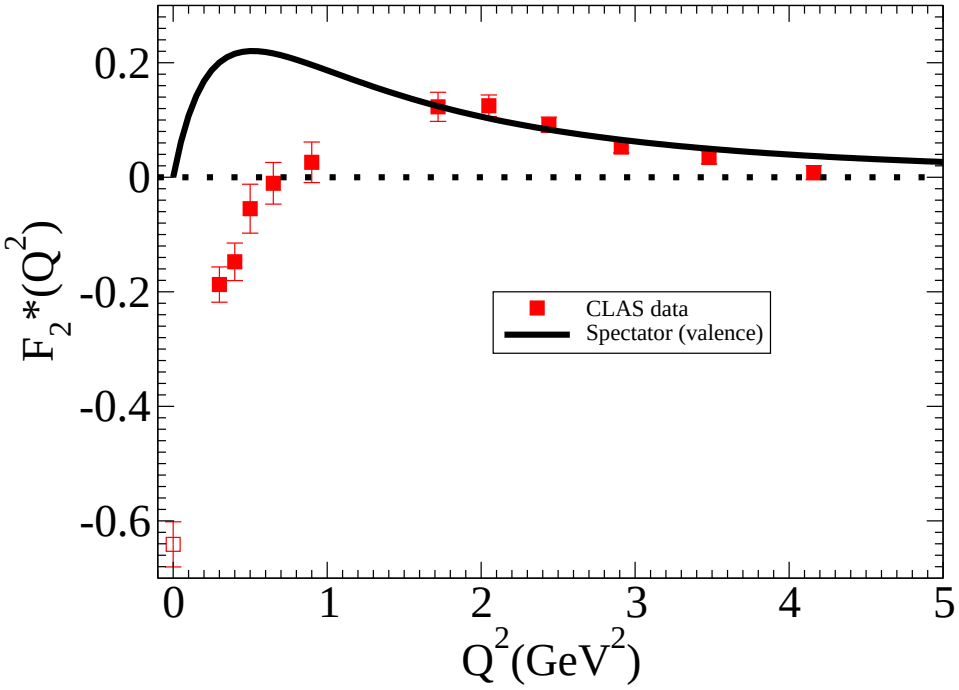

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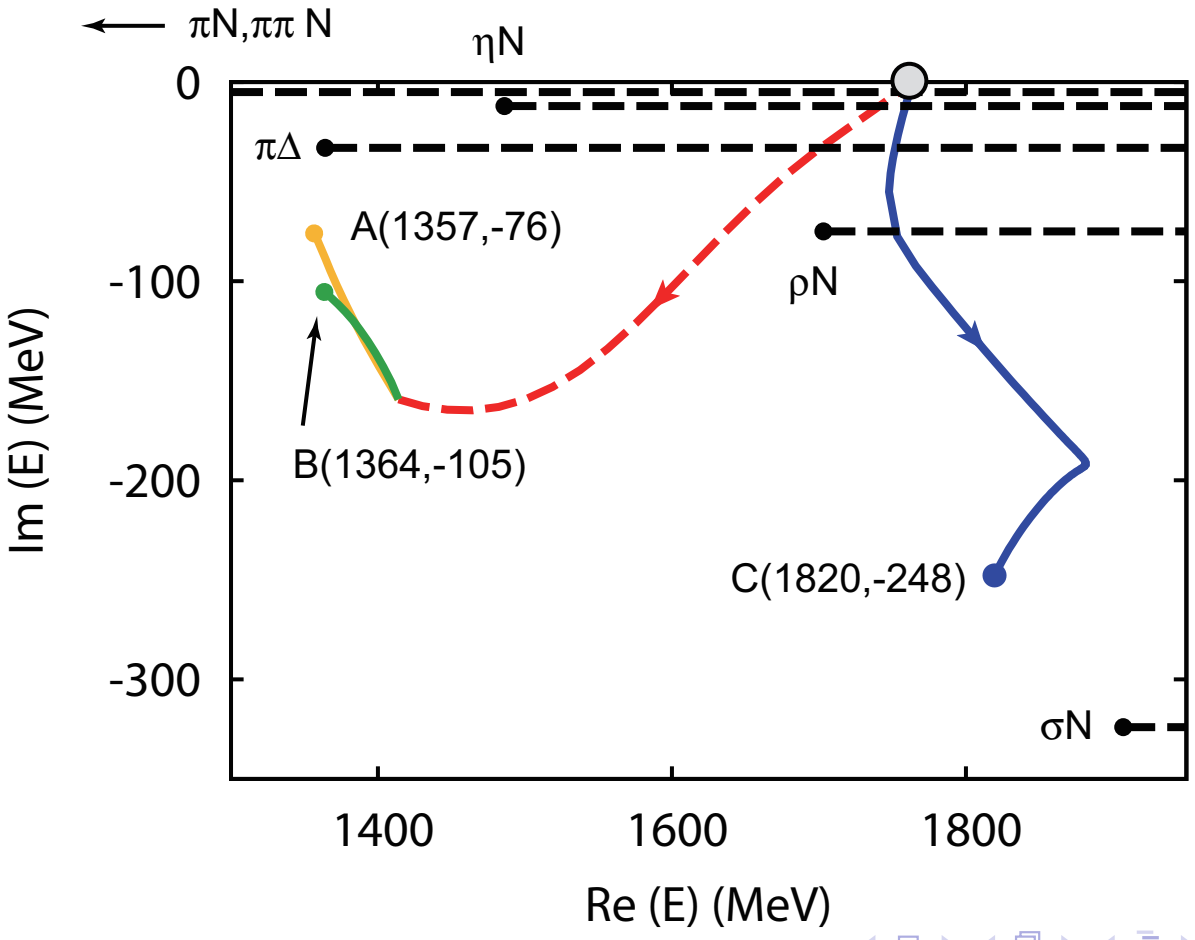
- $M_R = 1440$ MeV, Effect of the Roper mass ?

$\gamma N \longrightarrow$ Roper form factors- bare mass

Model with meson cloud dressing (EBAC)

Suzuki et al; PRL 104, 042302 (2010) – Bare mass: $M_R \approx 1750$ MeV



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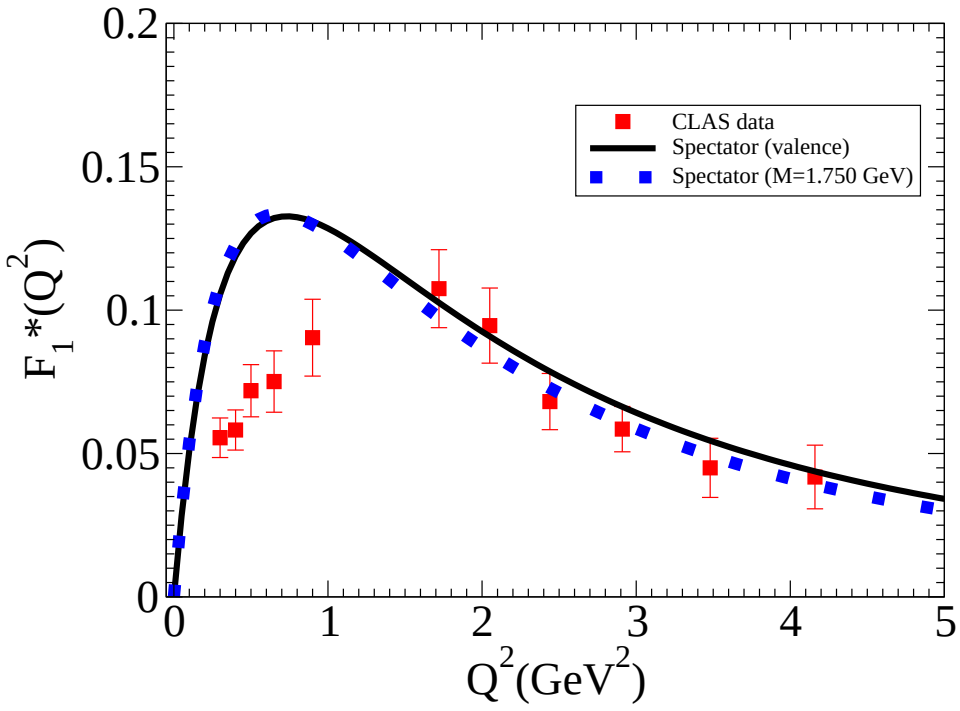
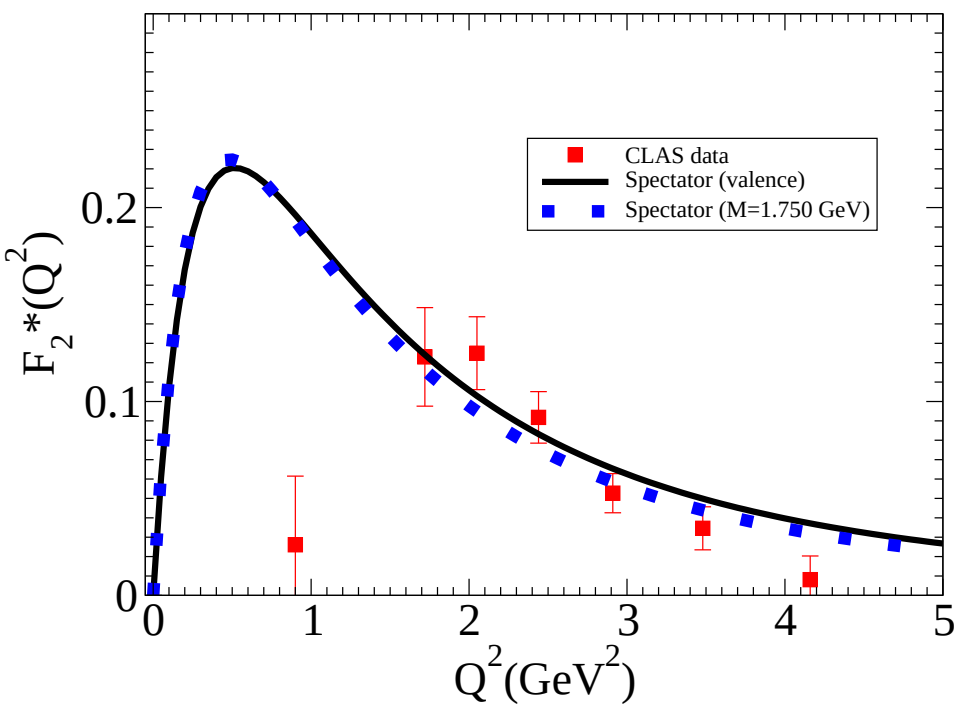
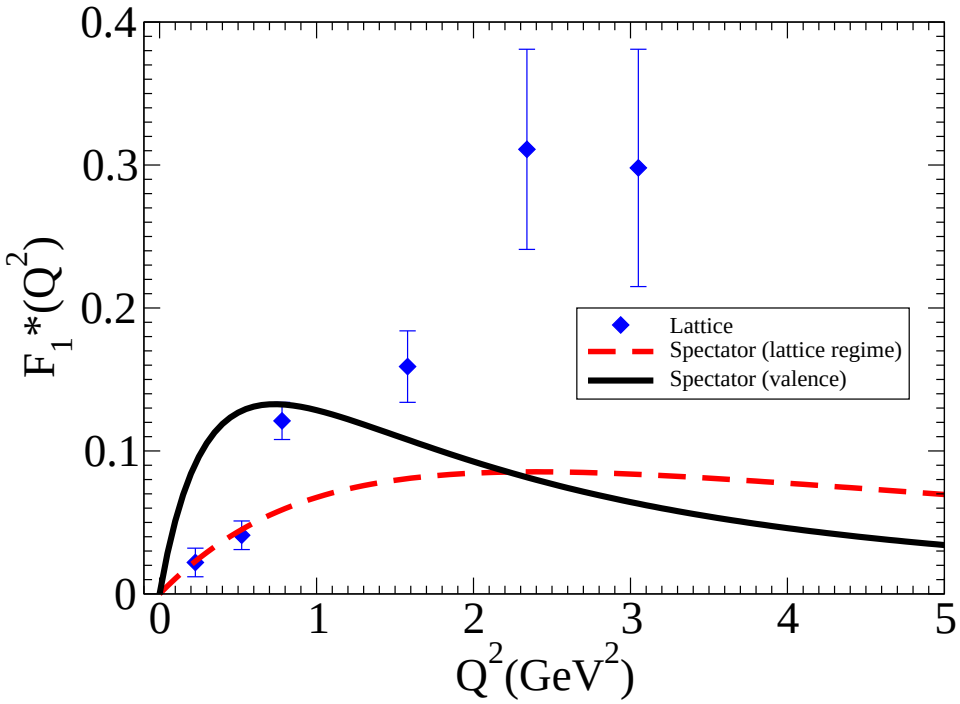
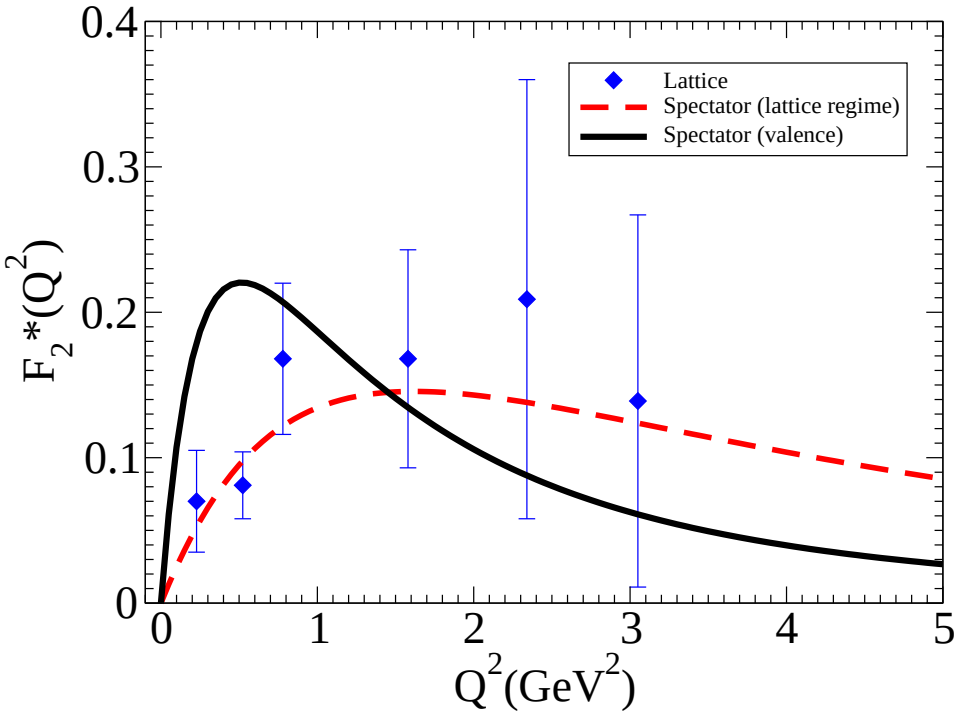




Form factors in lattice, [HW Lin et al PRD, 114508 (2008)]





- Extension for lattice

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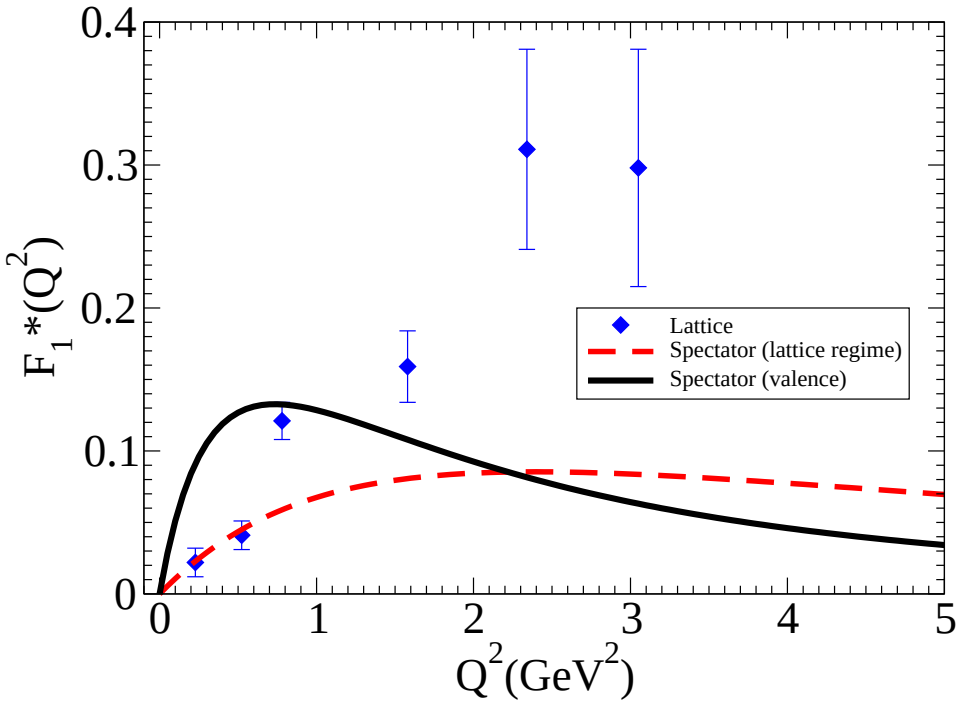

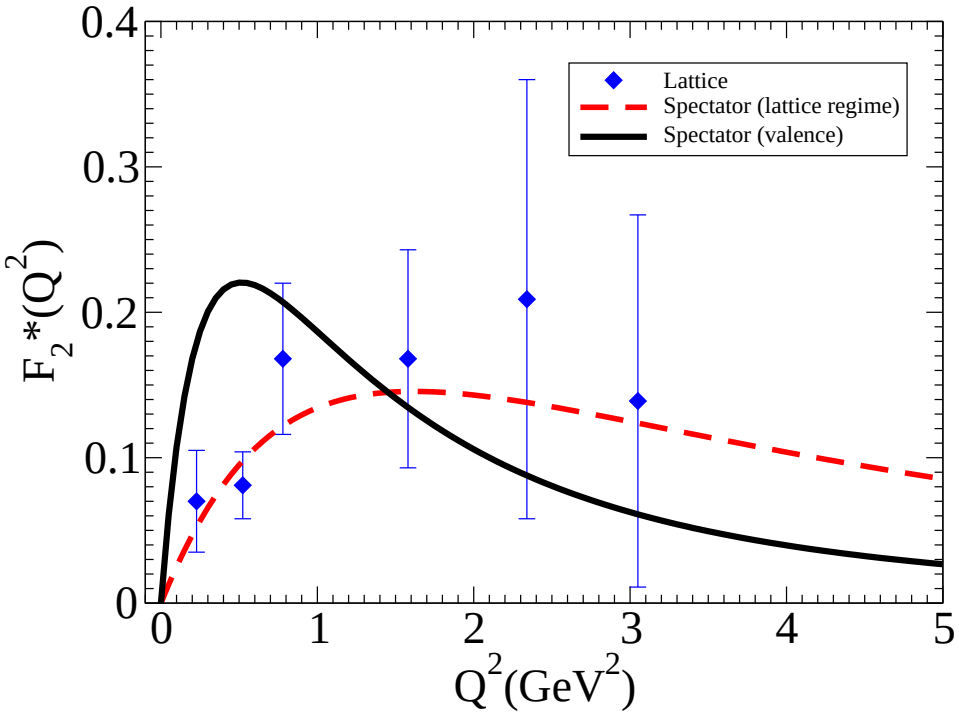

- Extension for lattice –Description of lattice data ($Q^2 < 1$ GeV^2)

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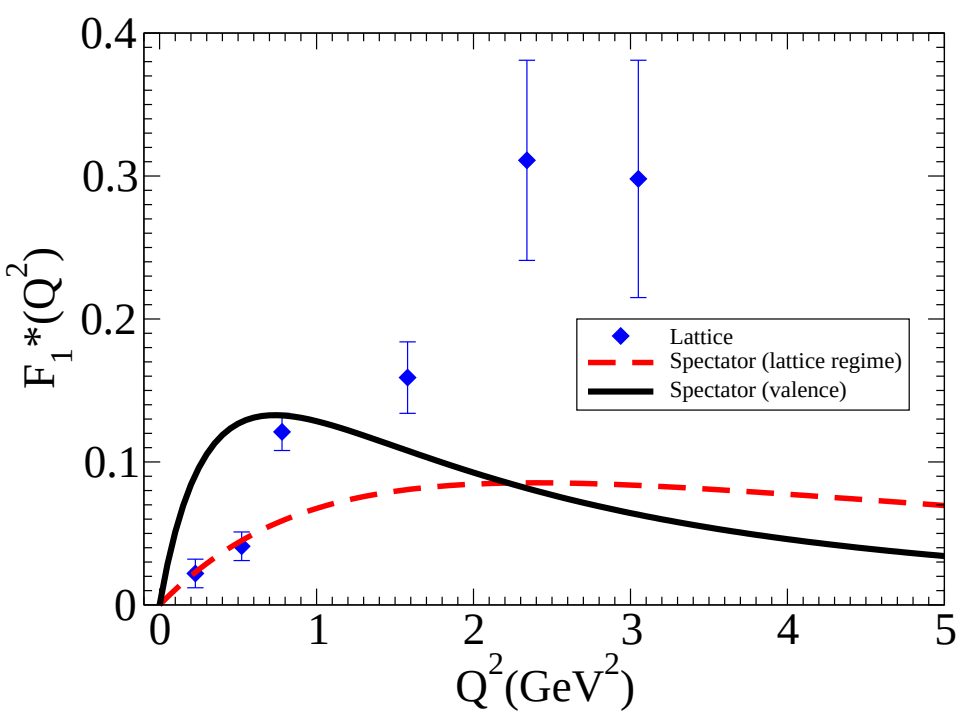

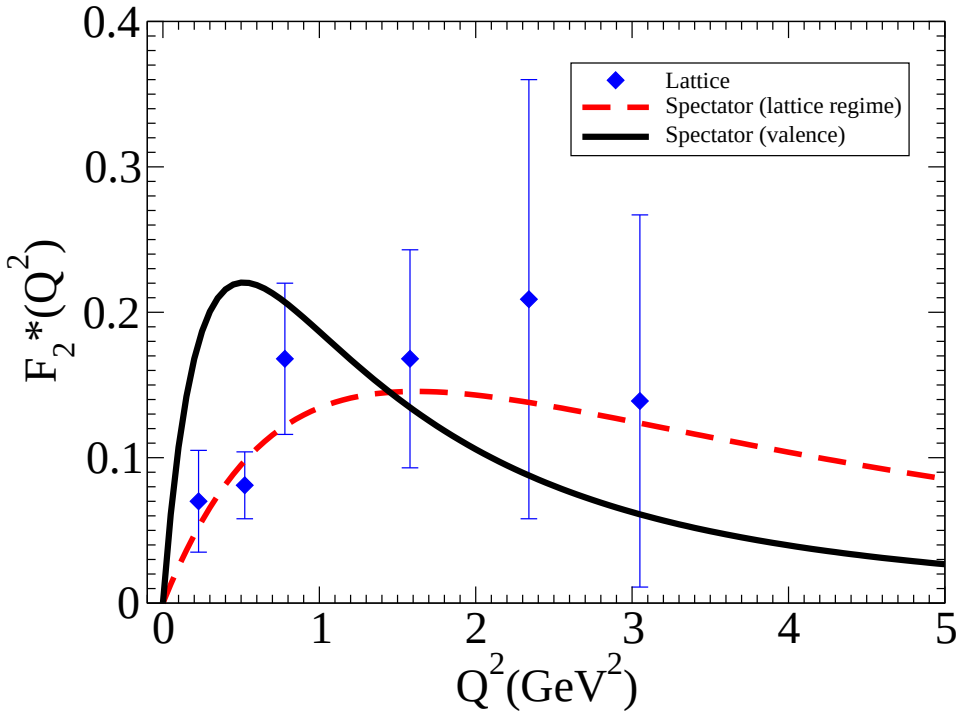

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- Good description of physical high Q^2 data

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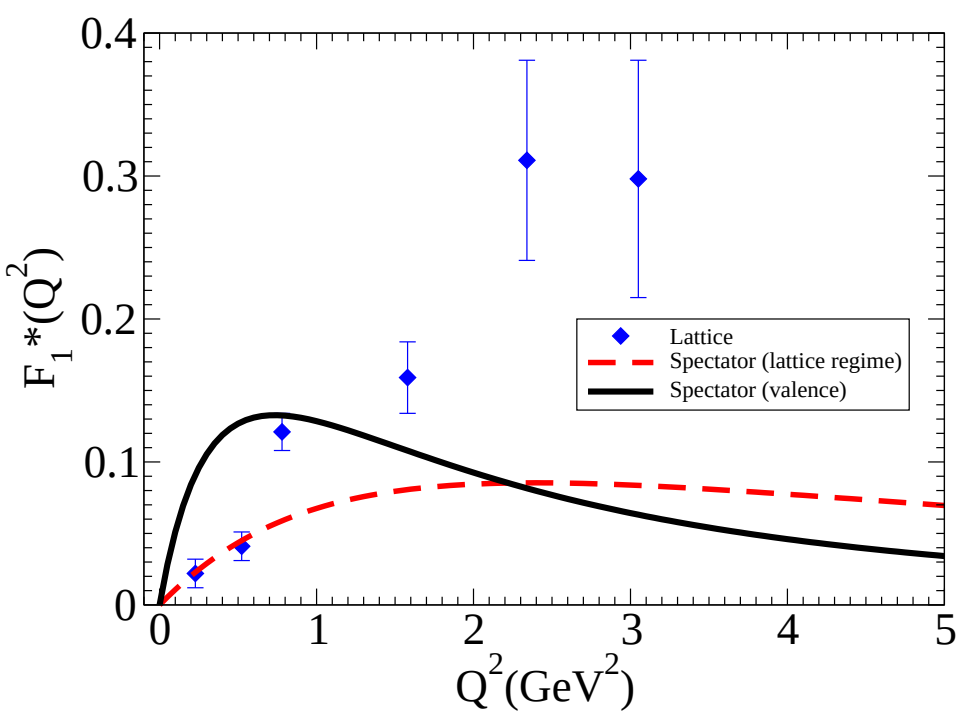

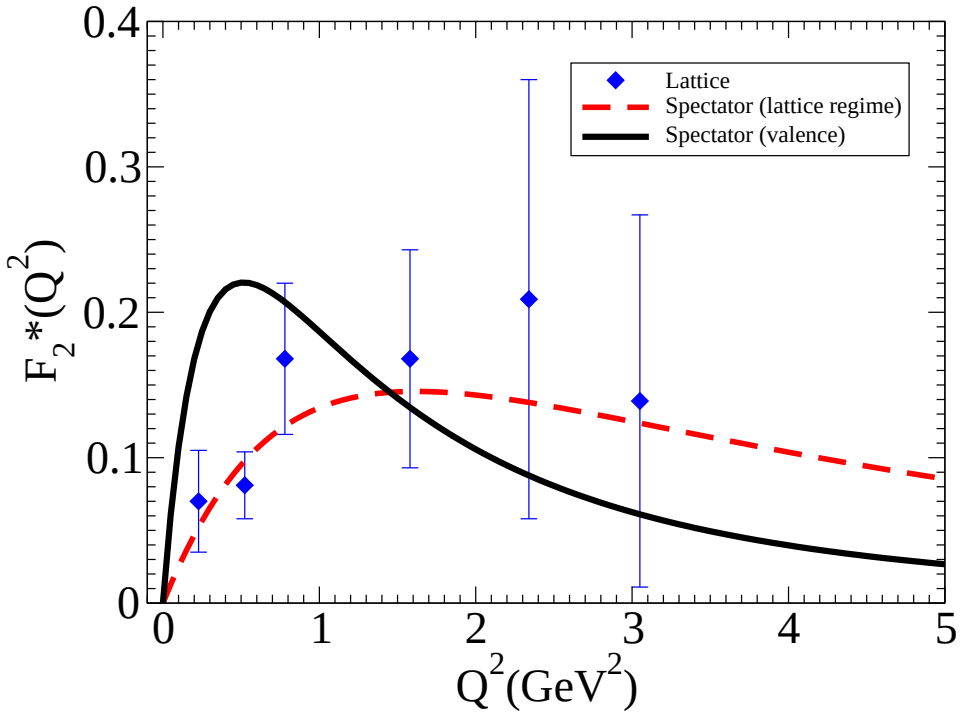

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- Good description of physical high Q^2 data
- $\Rightarrow$ valence quark contributions under **control**

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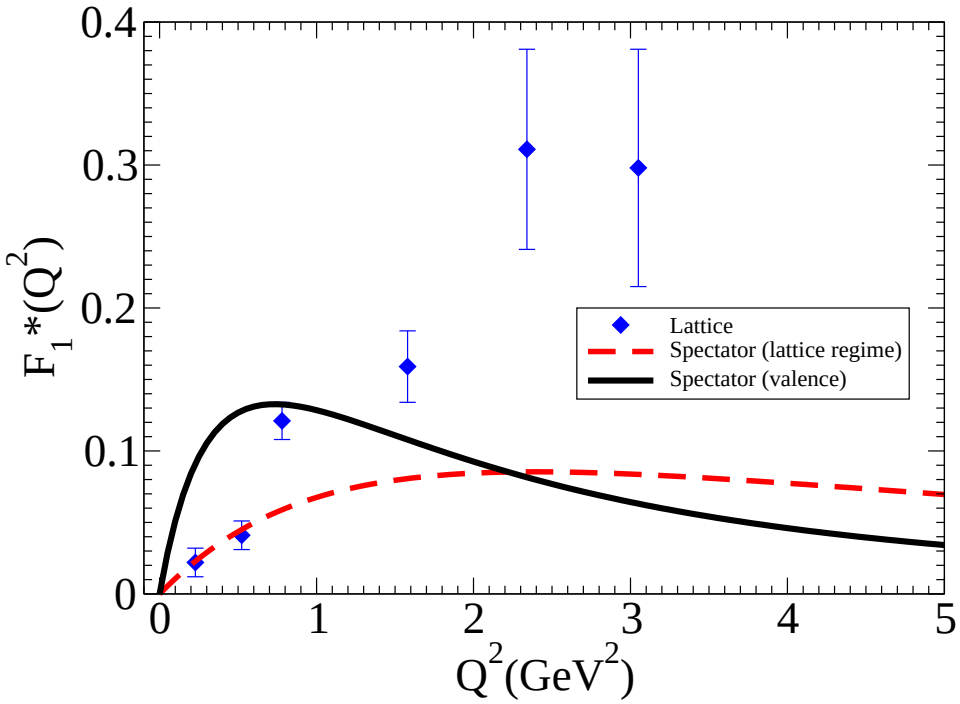
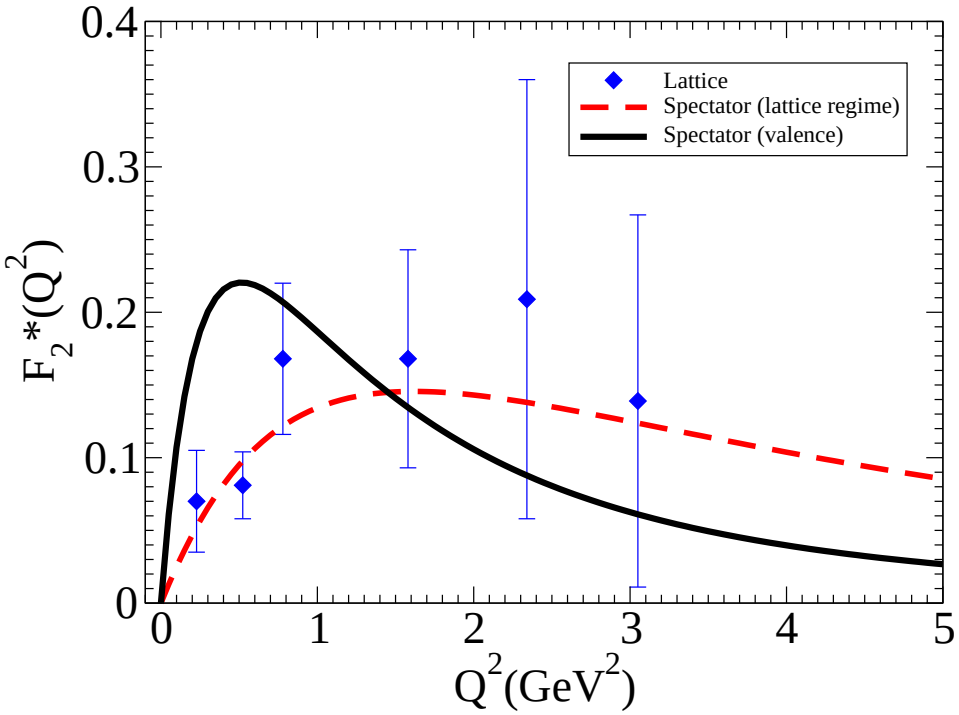
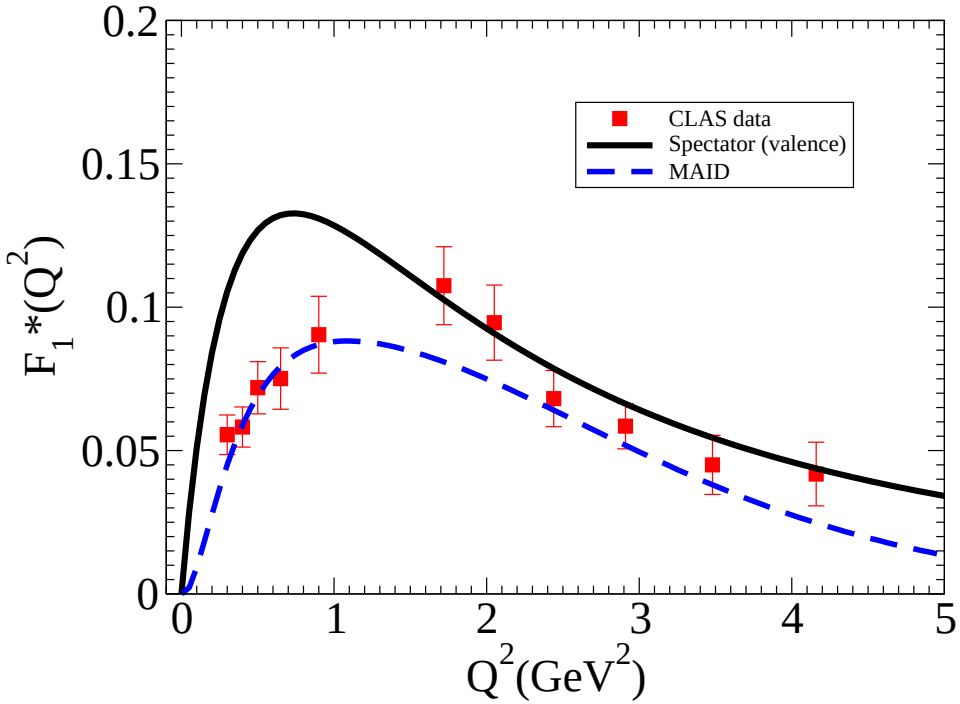
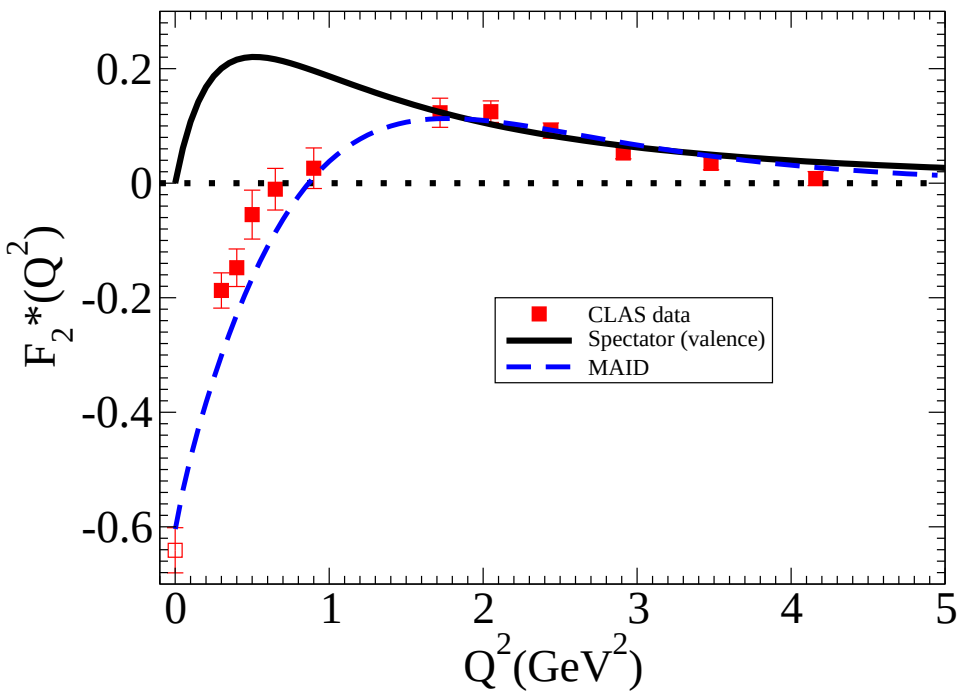




- Extension for lattice –Description of lattice data ($Q^2 < 1$ GeV^2)
- Good description of physical high Q^2 data
- $\Longrightarrow$ valence quark contributions under **control**
- $\Longrightarrow$ estimate meson cloud at low Q^2

$\gamma N \longrightarrow$ Roper form factors- results $\oplus$ MAID





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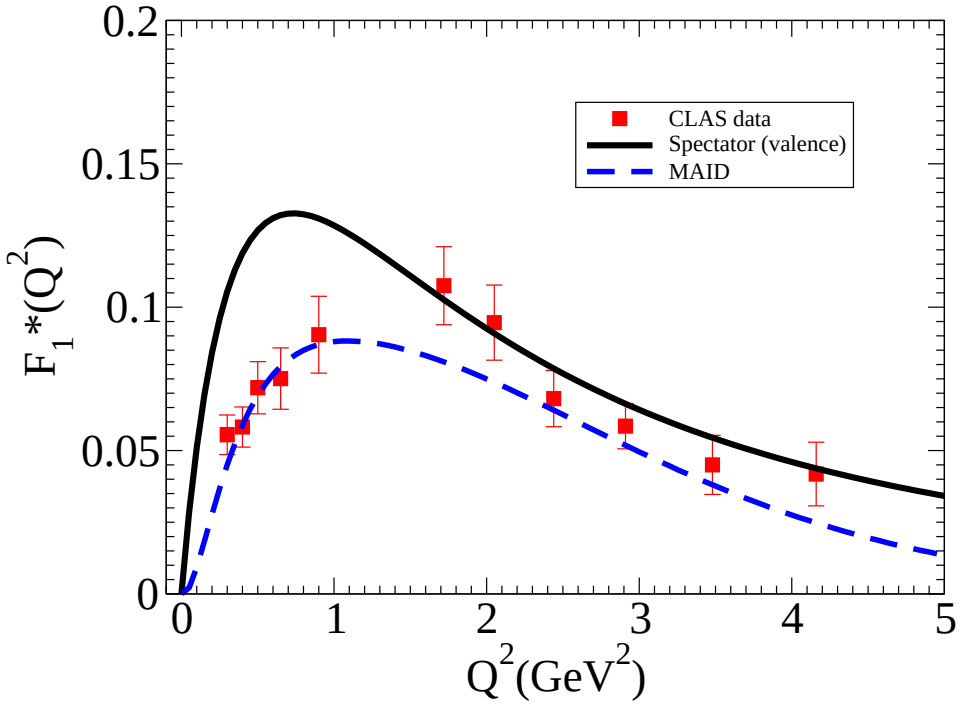
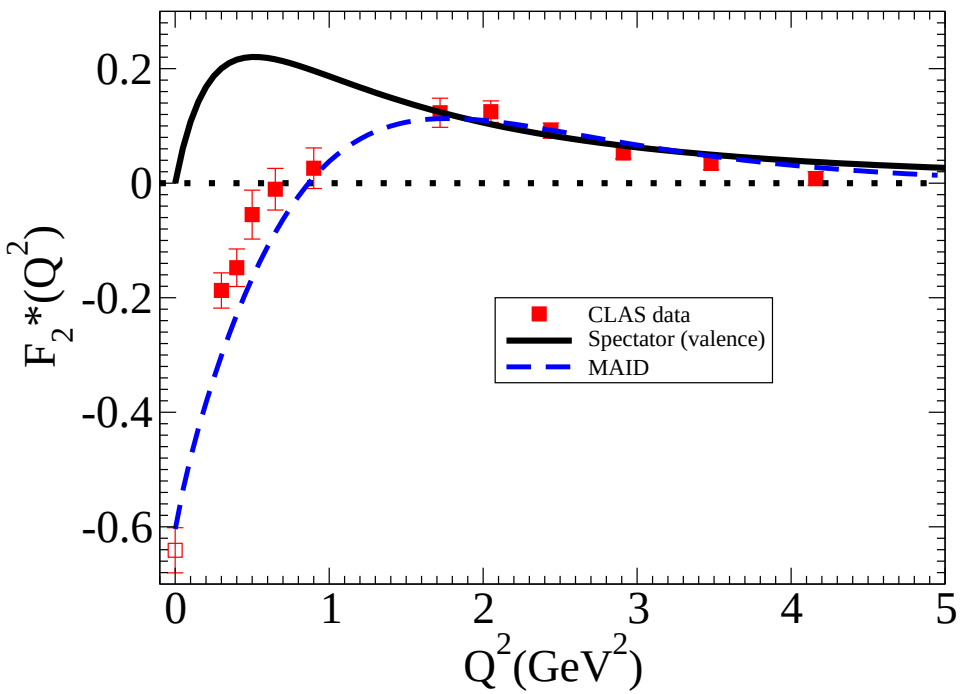
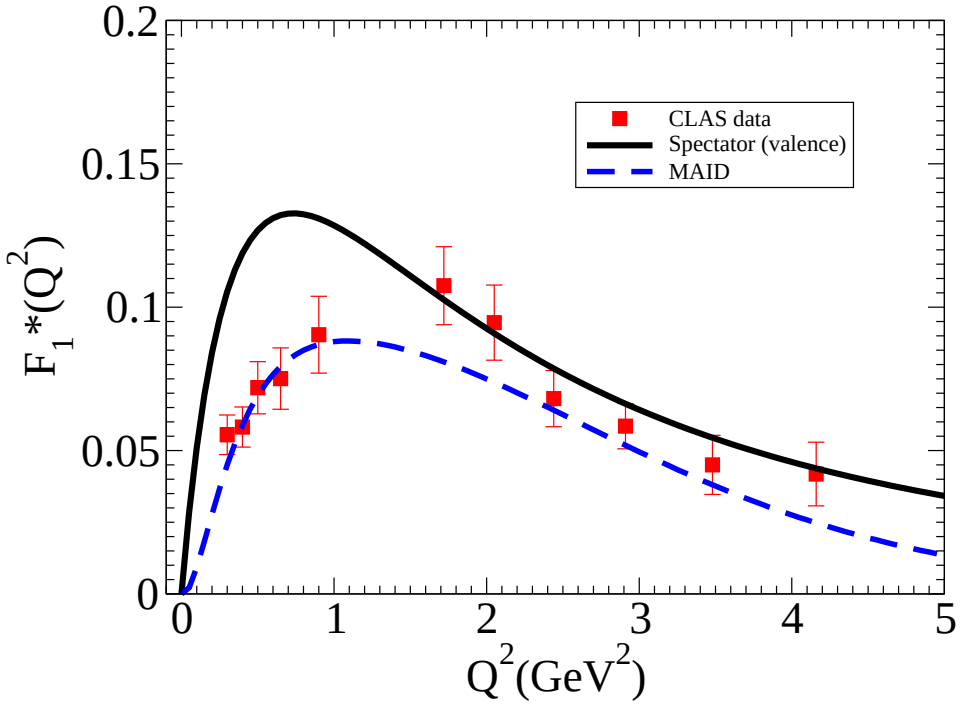
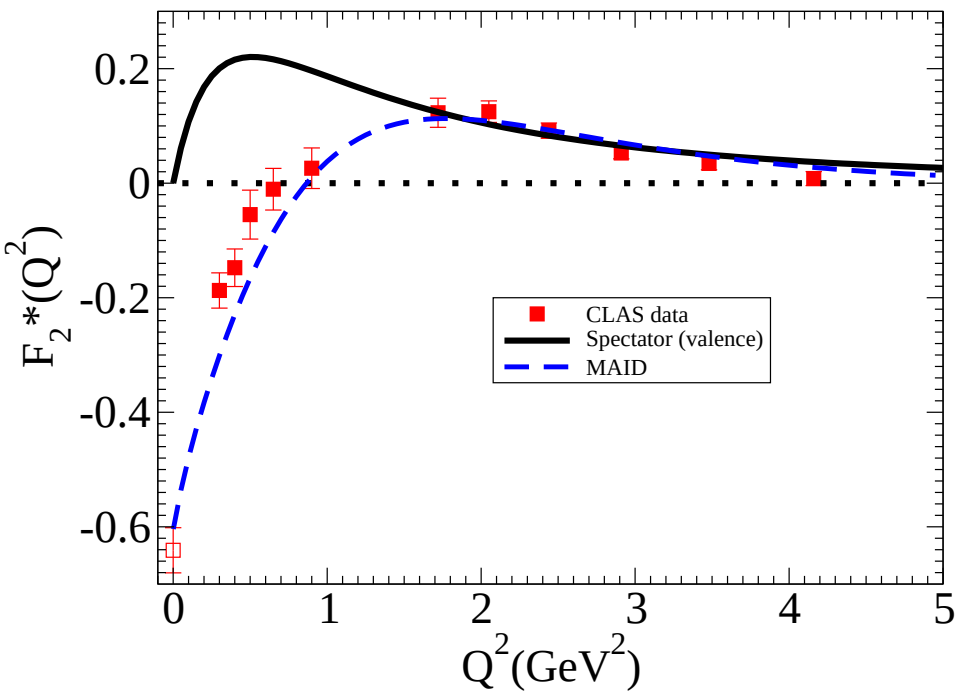




- **Spectator QM:** valence contributions F_i^{val}
- Compare with MAID fit F_i^* - Tiator et al PLB 672, 344 (2009)

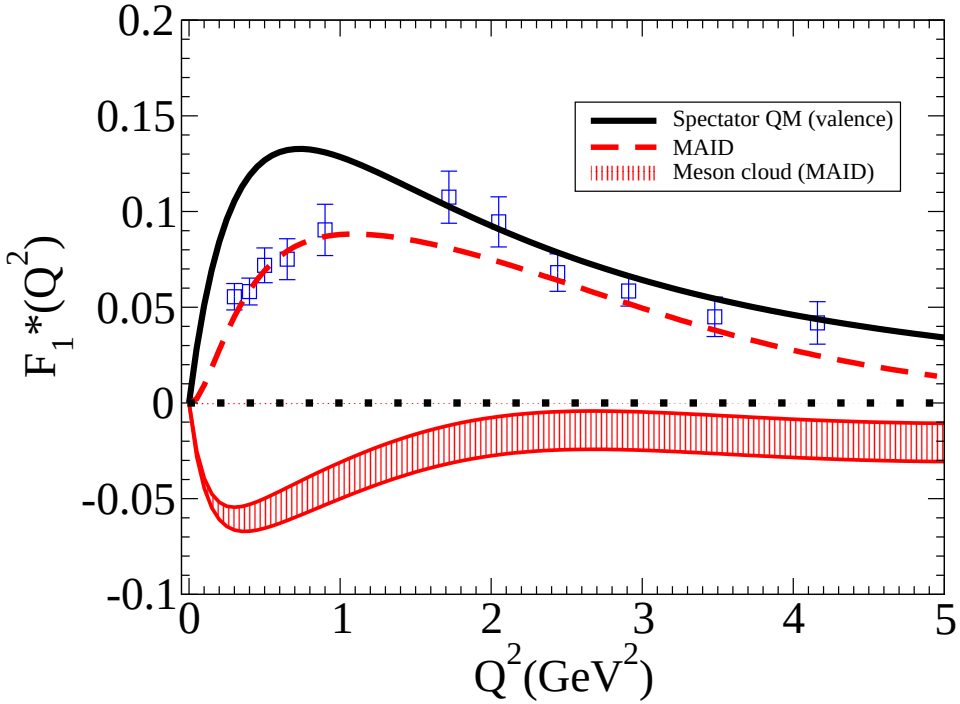
$\gamma N \longrightarrow$ Roper form factors- results $\oplus$ MAID

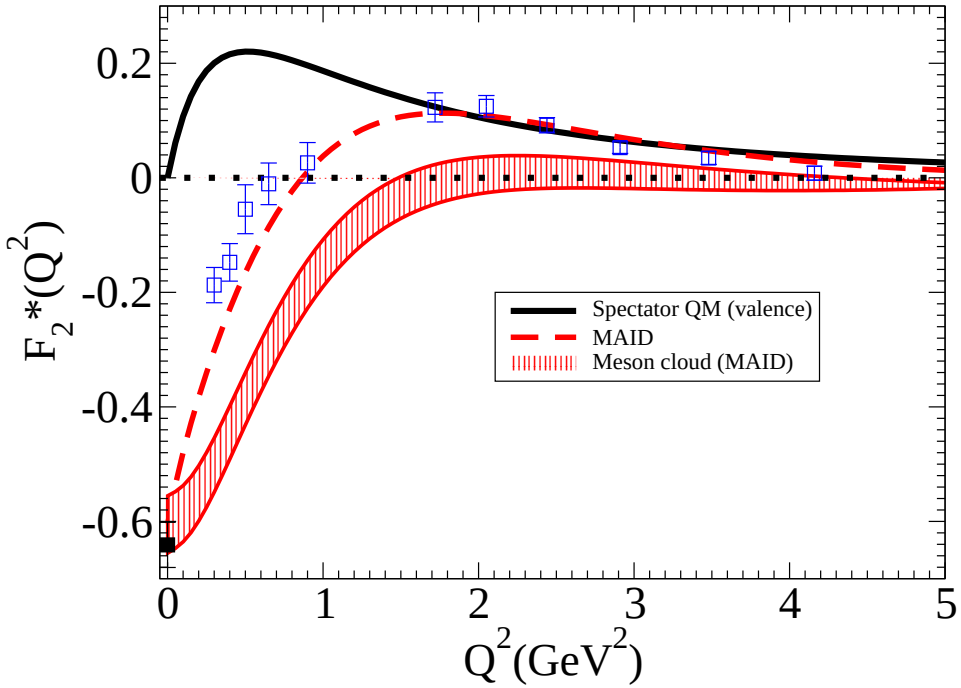




- **Spectator QM:** valence contributions F_i^{val}
- Compare with MAID fit F_i^* - Tiator et al PLB 672, 344 (2009)
- Meson cloud: $F_i^{mc} = F_i^* - F_i^{val}$

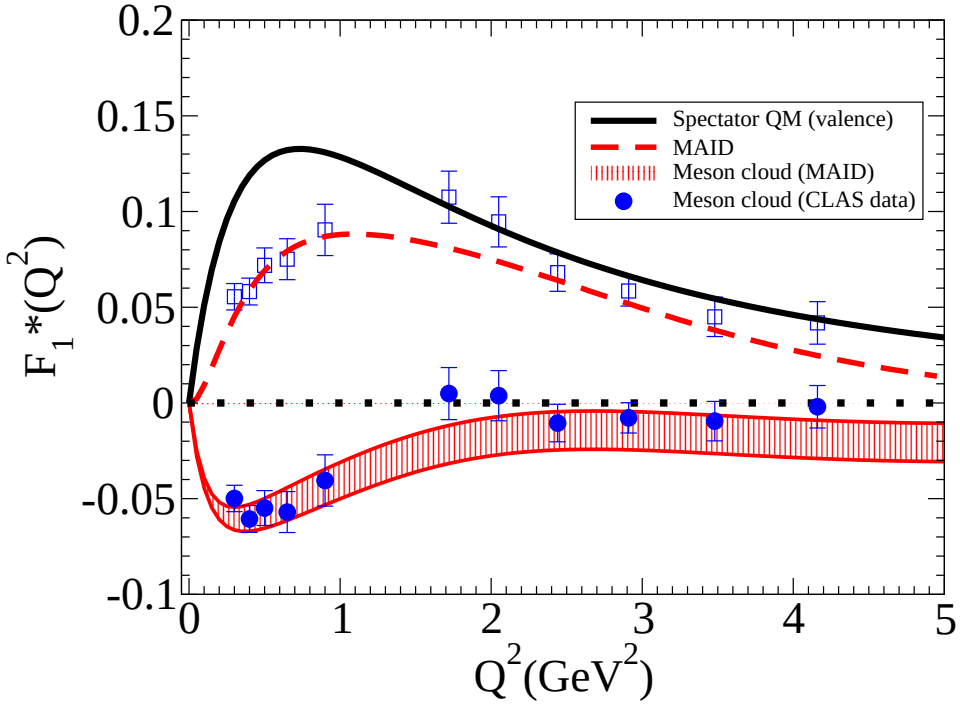
$\gamma N \longrightarrow$ Roper –Meson cloud contributions- MAID fit

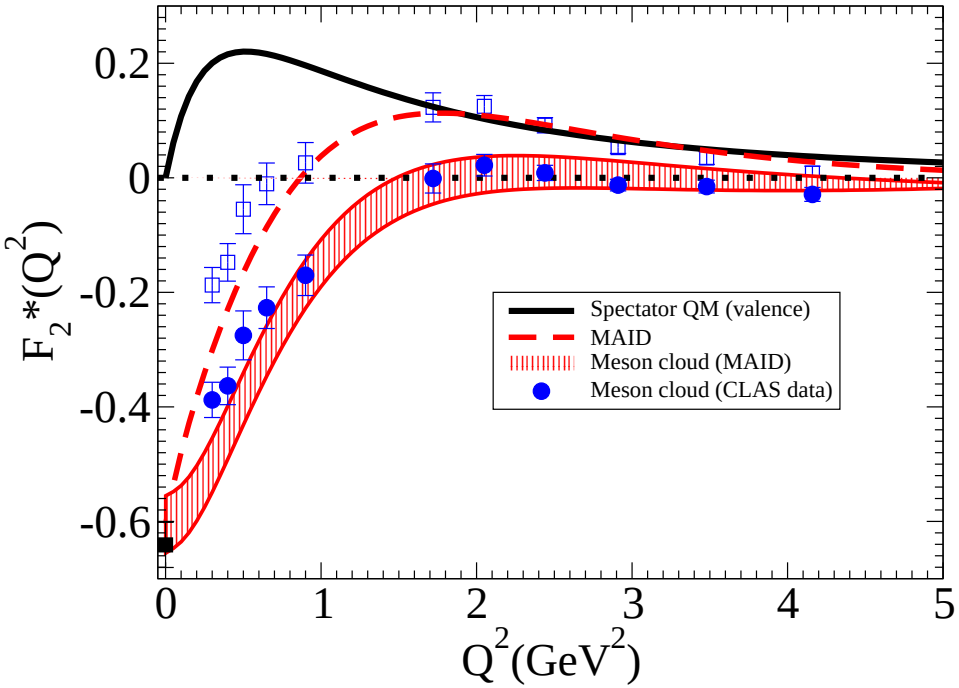




$$F_i^{mc}(Q^2) = F_i^*(Q^2) - F_i^{val}(Q^2) \qquad F_1^* \equiv F_1^{MAID}$$

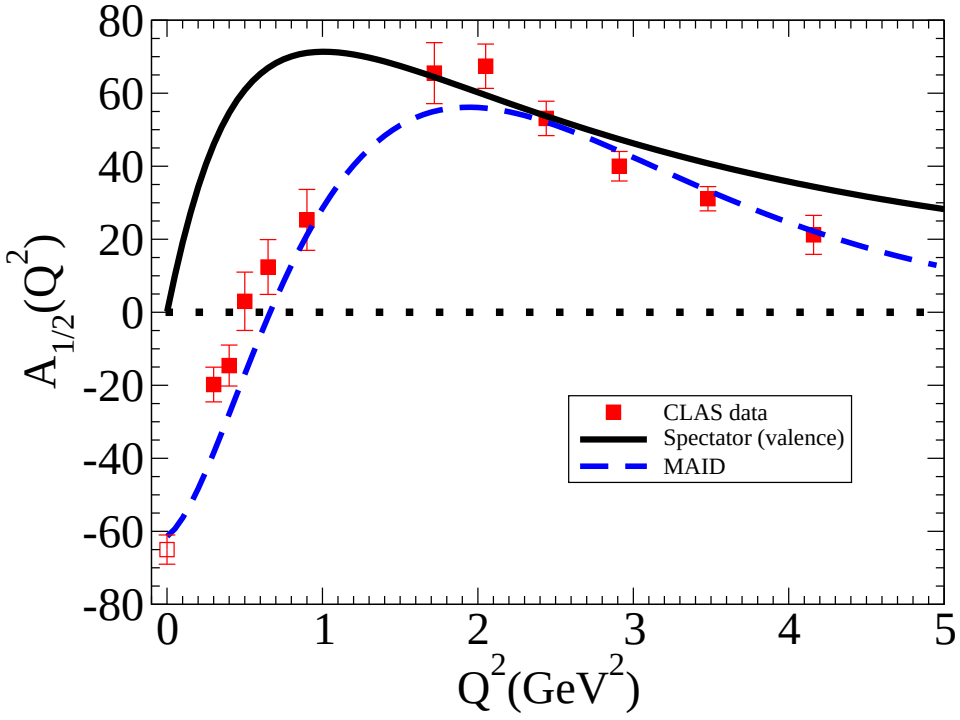
$\gamma N \longrightarrow$ Roper –Meson cloud contributions- CLAS

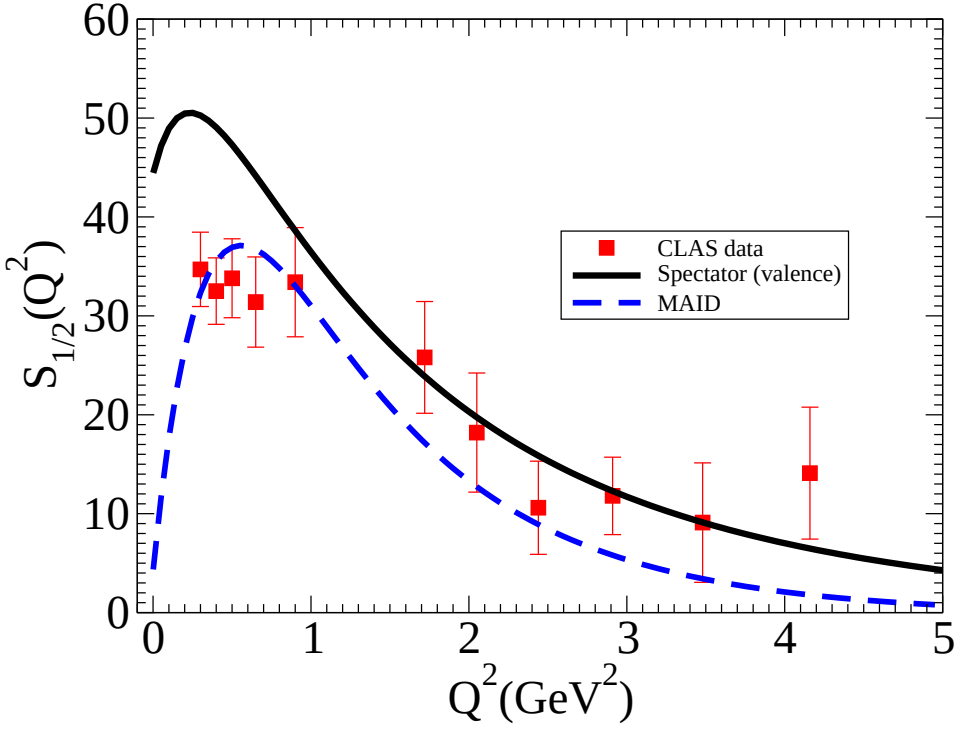




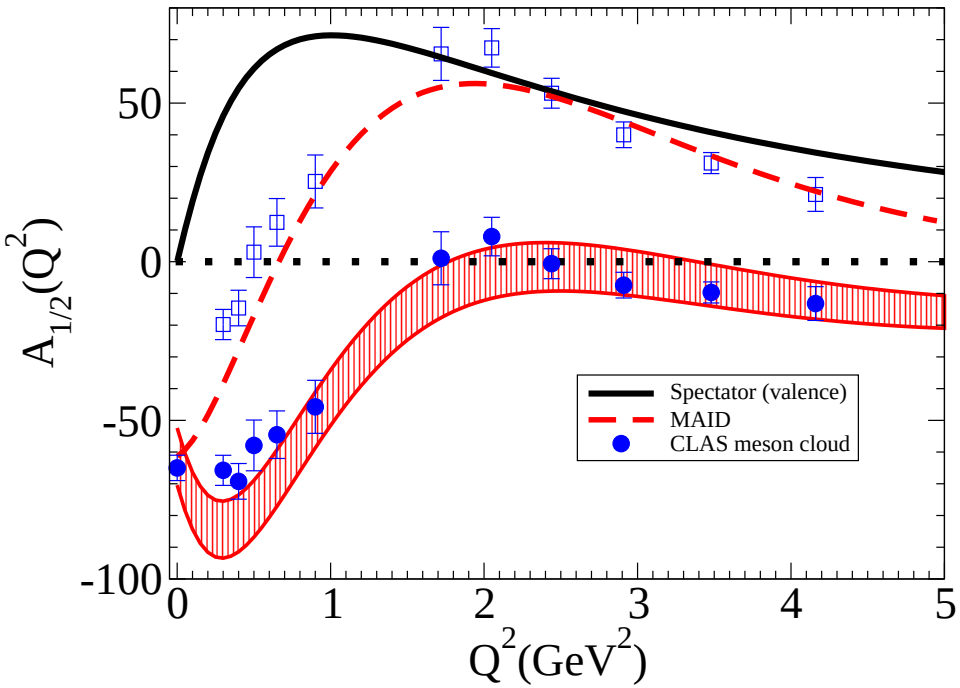
$$F_i^{mc}(Q^2) = F_i^*(Q^2) - F_i^{val}(Q^2) \qquad F_1^* \equiv F_1^{CLAS}$$

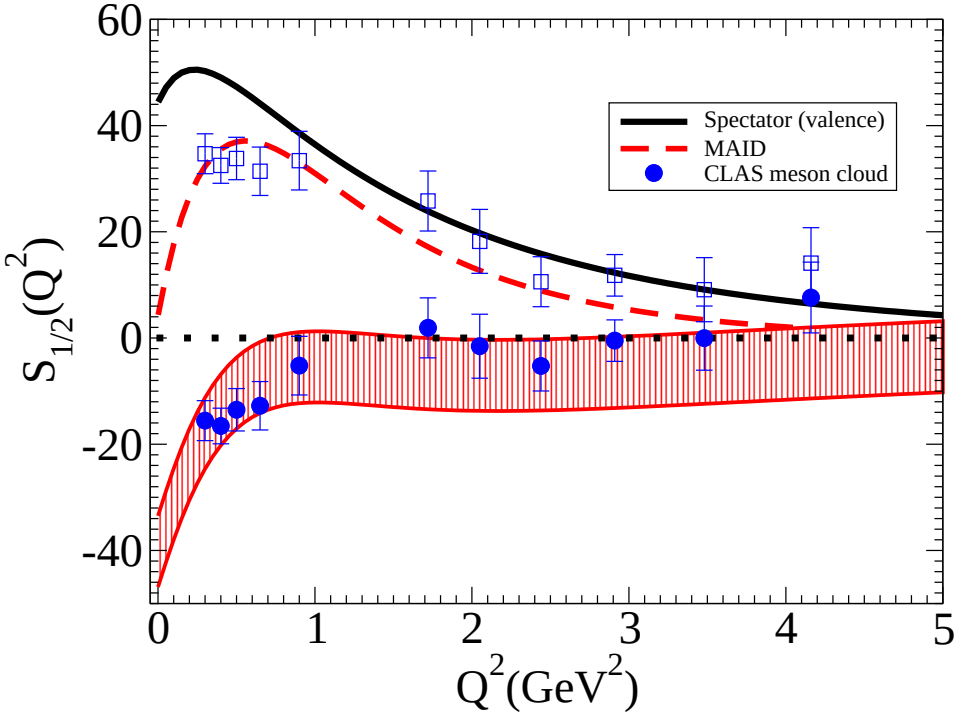
$\gamma N \longrightarrow$ Roper – Helicity amplitudes





$\gamma N \longrightarrow$ Roper – Helicity amplitudes -meson cloud





$$A_i^{mc}(Q^2) = A_i(Q^2) - A_i^{val}(Q^2)$$

$\gamma N \to$ Roper: Conclusions

- $\gamma N \to$ Roper
  Good description of high Q^2 data and lattice data [0 parameters]
  Valence quark degrees of freedom under **control**
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- Other applications:
  - Nucleon form factors PRC 77, 015202 (2008)
  - $\gamma N \to \Delta$ transition: PRD 78, 114017 (2008); PRD 80, 013008 (2009)
  - Ω^- form factors PRD**80**, 033004 (2009)
  - Δ form factors arXiv:1002.4170 [hep-ph], PLB 678, 355 (2009)
  - Octet magnetic moments (w/ pion cloud) arXiv:0910.2171 [hep-ph]
  - Form factors in lattice JPG**36**, 115011 (2009)

Thank you 

Bibliography (part 1)

- **A pure S-wave covariant model for the nucleon**,
  F. Gross, G. Ramalho and M. T. Peña, Phys. Rev. C **77**, 015202 (2008).
- **Fixed-axis polarization states: covariance and comparisons,**
  F. Gross, G. Ramalho and M. T. Peña, Phys. Rev. C **77**, 035203 (2008).
- **A Covariant model for the nucleon and the Δ**,
  G. Ramalho, M. T. Peña and F. Gross, Eur. Phys. J. A **36**, 329 (2008).
- **D-state effects in the electromagnetic $N - \Delta$ transition**,
  G. Ramalho, M. T. Peña and F. Gross, Phys. Rev. D **78**, 114017 (2008).
- **Nucleon and $\gamma N \to \Delta$ lattice form factors in a constituent quark model,**
  G. Ramalho and M. T. Peña, J. Phys. G **36**, 115011 (2009).
- **Valence quark contribution for the $\gamma N \to \Delta$ quadrupole transition extracted from lattice QCD**,
  G. Ramalho and M. T. Peña, Phys. Rev. D **80**, 013008 (2009).

Bibliography (part 2)

- **Electromagnetic form factors of the Delta in a S-wave approach**, G. Ramalho and M. T. Peña, J. Phys. G **36**, 085004 (2009).
- **A relativistic quark model for the Ω^- electromagnetic form factors**, G. Ramalho, K. Tsushima and F. Gross, Phys. Rev. D **80**, 033004 (2009).
- **Using baryon octet magnetic moments and masses to fix the pion cloud contribution**, to appear in PLB, F. Gross, G. Ramalho and K. Tsushima, arXiv:0910.2171 [hep-ph].
- **Electric quadrupole and magnetic octupole moments of the Δ**, G. Ramalho, M. T. Peña and F. Gross, Phys. Lett. B **678**, 355 (2009).
- **Electromagnetic form factors of the Δ in a D-wave approach**, G. Ramalho, M. T. Peña and Franz Gross, arXiv:1002.4170 [hep-ph]
- **Valence quark contributions for the $\gamma N \to P_{11}(1440)$ form factors**, G. Ramalho and K. Tsushima, Phys. Rev. D **81**, 074020 (2010).