Form factors and the G_E/G_M ratio

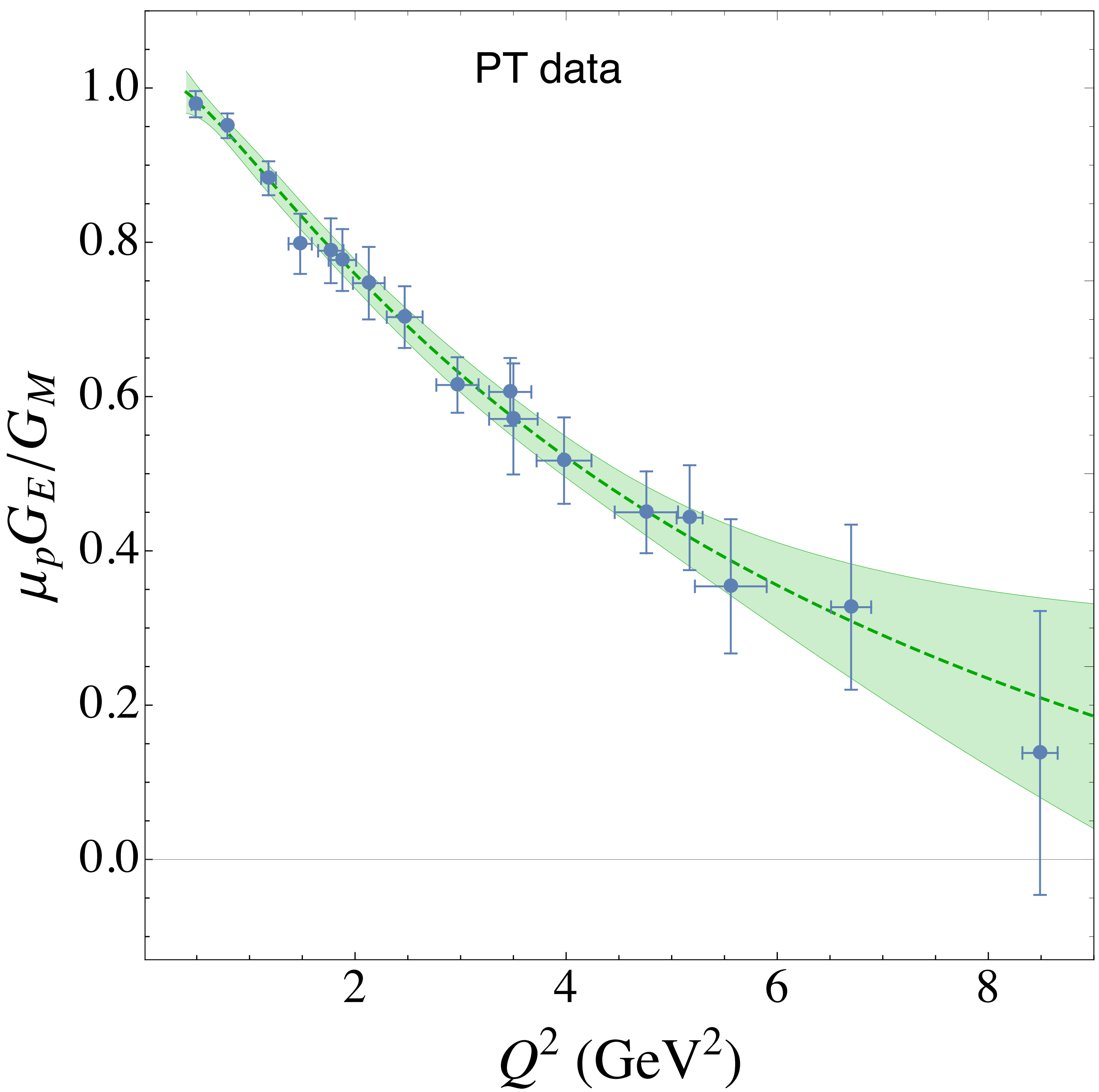
SLAC E140/NE11 LT: Walker *et al*, PRD **49**, 5671 (1994); Andivahis *et al*, PRD **50**, 5491 (1994)

Super Rosenbluth LT: Qattan *et al*, PRL **94**, 5671 (1994)

Polarization Transfer (PT): (various)

$$1\ \mathrm{GeV}^2 \le Q^2 \le 8.83\ \mathrm{GeV}^2$$

- To extract G_E and G_M from LT measurements we should correct the **data** for TPE at the same level as other RCs.
- SLAC: all details of RC are published
- Super Rosenbluth: no details are published, not even cross sections!



- Band is at 99% confidence interval

SLAC formulation: Walker *et al.* PRD **49**, 5671 (1994)

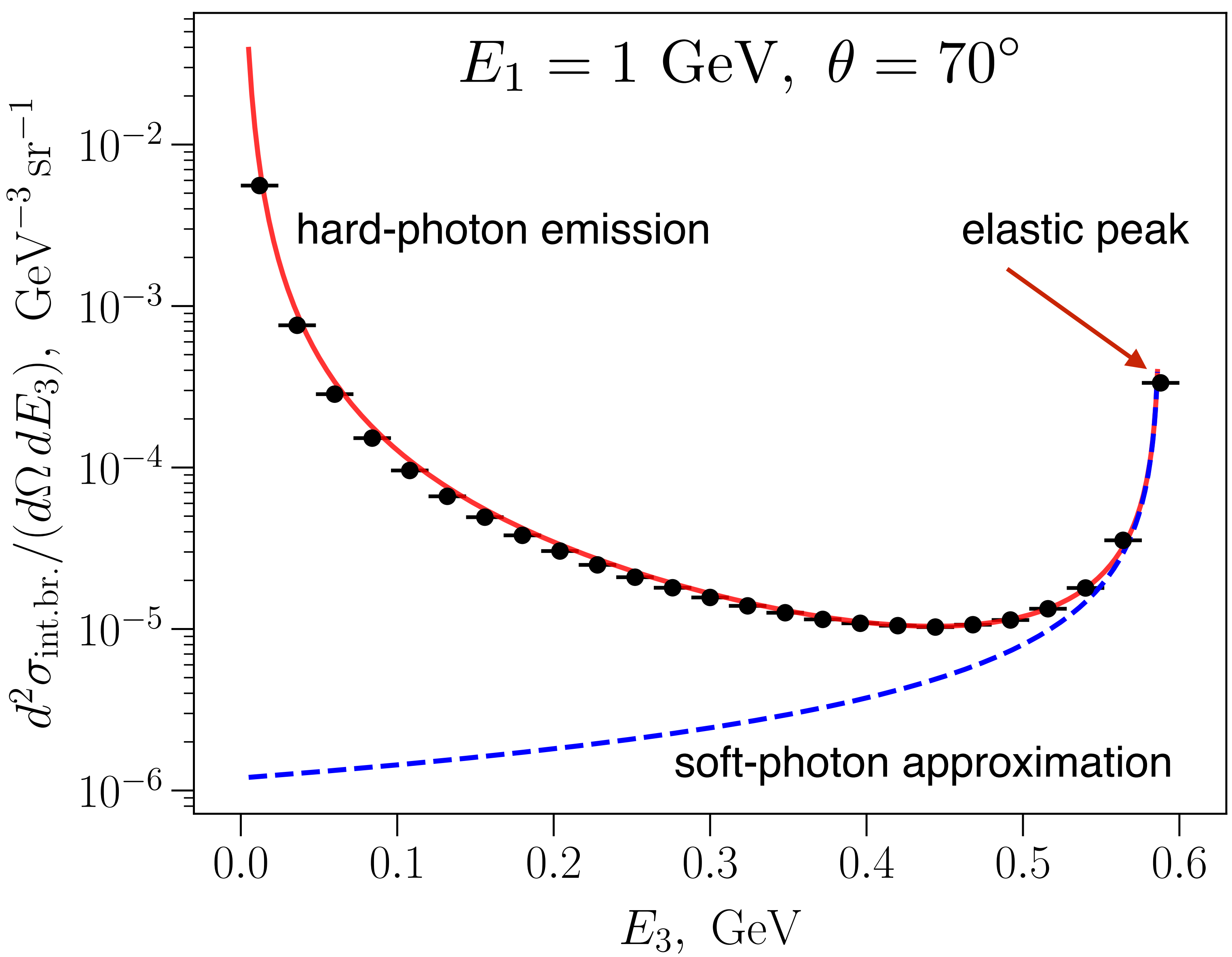
$$\sigma_R^{\text{meas}} = C_{\text{RC}}^{\text{old}} \left(\sigma_R^{\text{Born}}\right)^{\text{old}} = C_{\text{RC}}^{\text{new}} \left(\sigma_R^{\text{Born}}\right)^{\text{new}}$$

$$\begin{aligned} C_{\text{RC}} &= C_L \exp\left(\delta_{\text{RC}} + \delta\right), \\ \delta_{\text{RC}} &= \delta(\text{MTj}) + \delta_{\text{VP}} + \delta_{\text{brem,int}} + \delta_{\text{brem,ext}}, \\ \delta &= \delta_{\text{TPE}} - \delta_{\text{IR}}(\text{MTj}) \end{aligned}$$

MTs = Mo-Tsai
MTj = Maximon-Tjon

RC improvements: Gramolin & Nikolenko, PRC **93**, 055201 (2016)

- Use exponentiation
- Use Maximon-Tjon instead of Mo-Tsai (no difference at order Z^0)
- Improvements to hard internal and external δ_{brem} bremsstrahlung
- Minor improvements to VP and ionization factor C_L



A forgotten term, and a little known fact

- A correction by Schwinger[1] was included by Tsai to correct for the non-IR divergent part of the soft photon emission cross section for electrons.
- A sign error in Tsai's paper was found in 1987[2], and the additional term

$$\delta_{\mathrm{Sch}} = \frac{\alpha}{\pi}\left[\mathrm{Li}_2\left(\cos^2(\theta/2)\right) - \frac{\pi^2}{6}\right].$$

  was included in the SLAC analyses. It seems to have been forgotten ever since.

- If we look at Z^0 terms **only**:

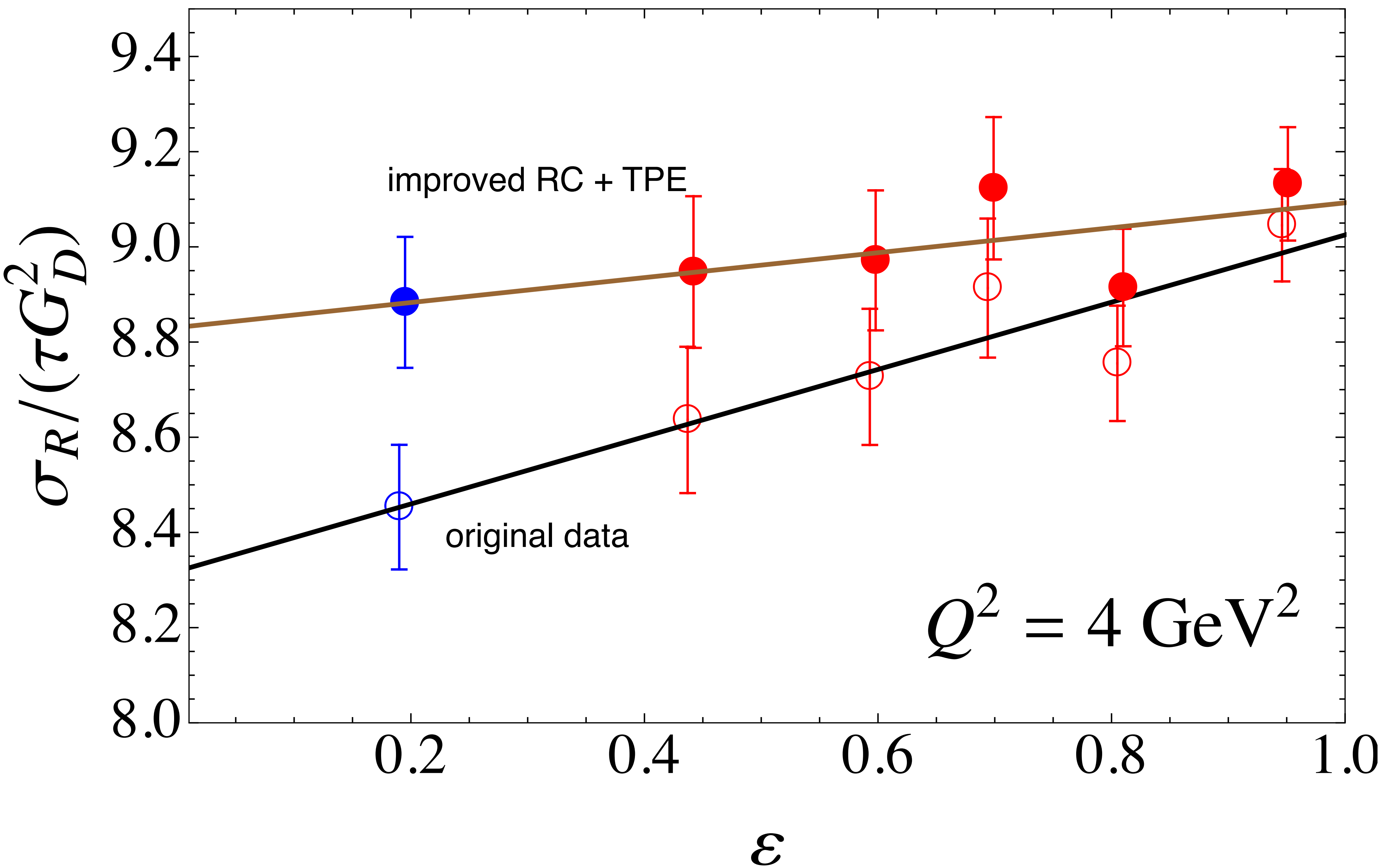
$$\delta(\mathrm{MTs}) + \delta_{\mathrm{Sch}} = \delta(\mathrm{MTj})$$

- So there are **no differences** between Mo-Tsai and Maximon-Tjon for Z^0 terms (as it should be, since this is pure QED)!
- There are still differences for the smaller Z^1 and Z^2 terms.

[1]Schwinger, Phys. Rev. **76**, 790 (1949)

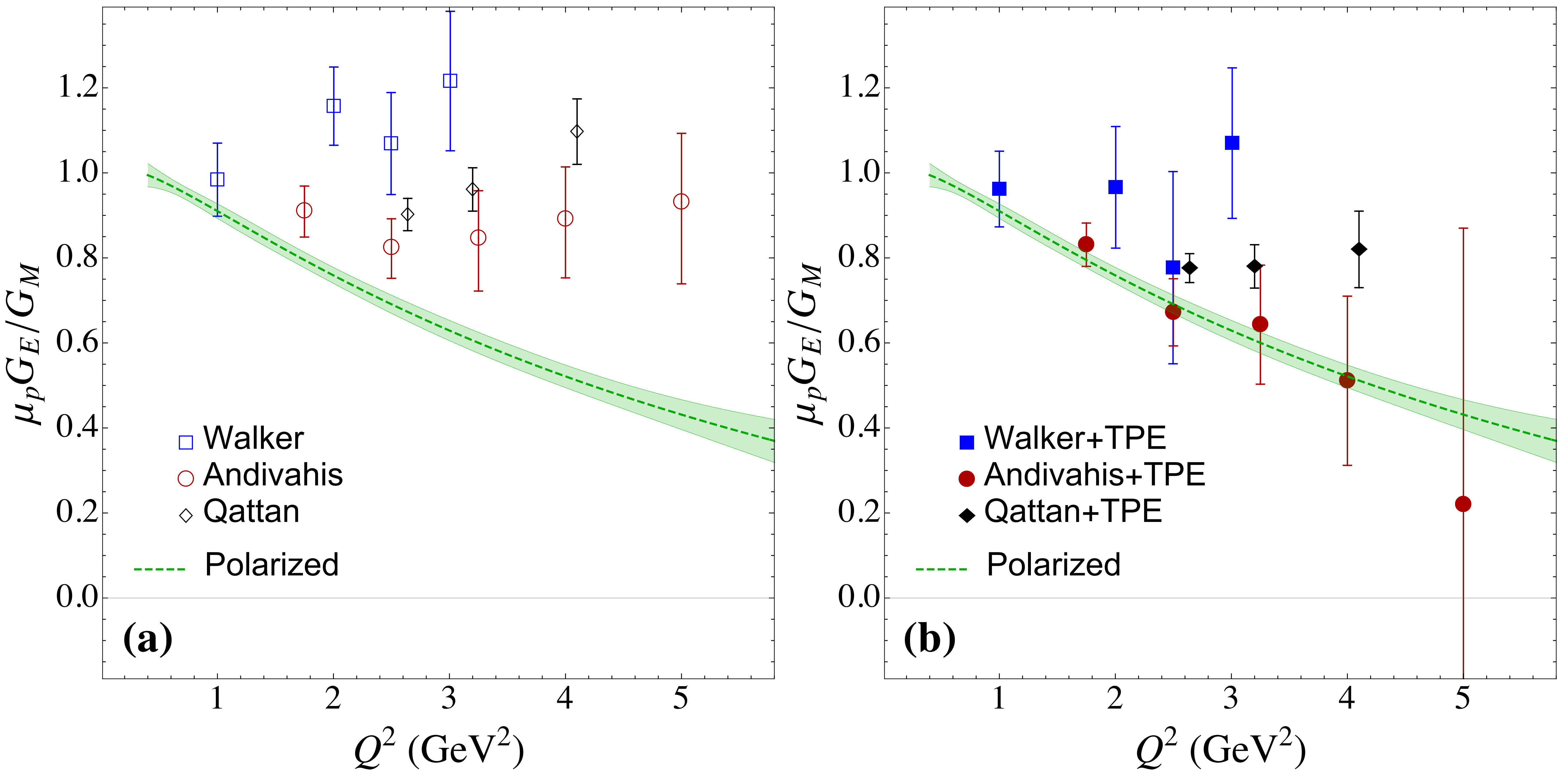
[2]Marchand, Ph.D. thesis, L'Université de Paris-SUD, Centre D'Orsay, 1987

$$\sigma_{\mathrm{red}} = G_M^2 + \frac{\varepsilon}{\tau} G_E^2$$



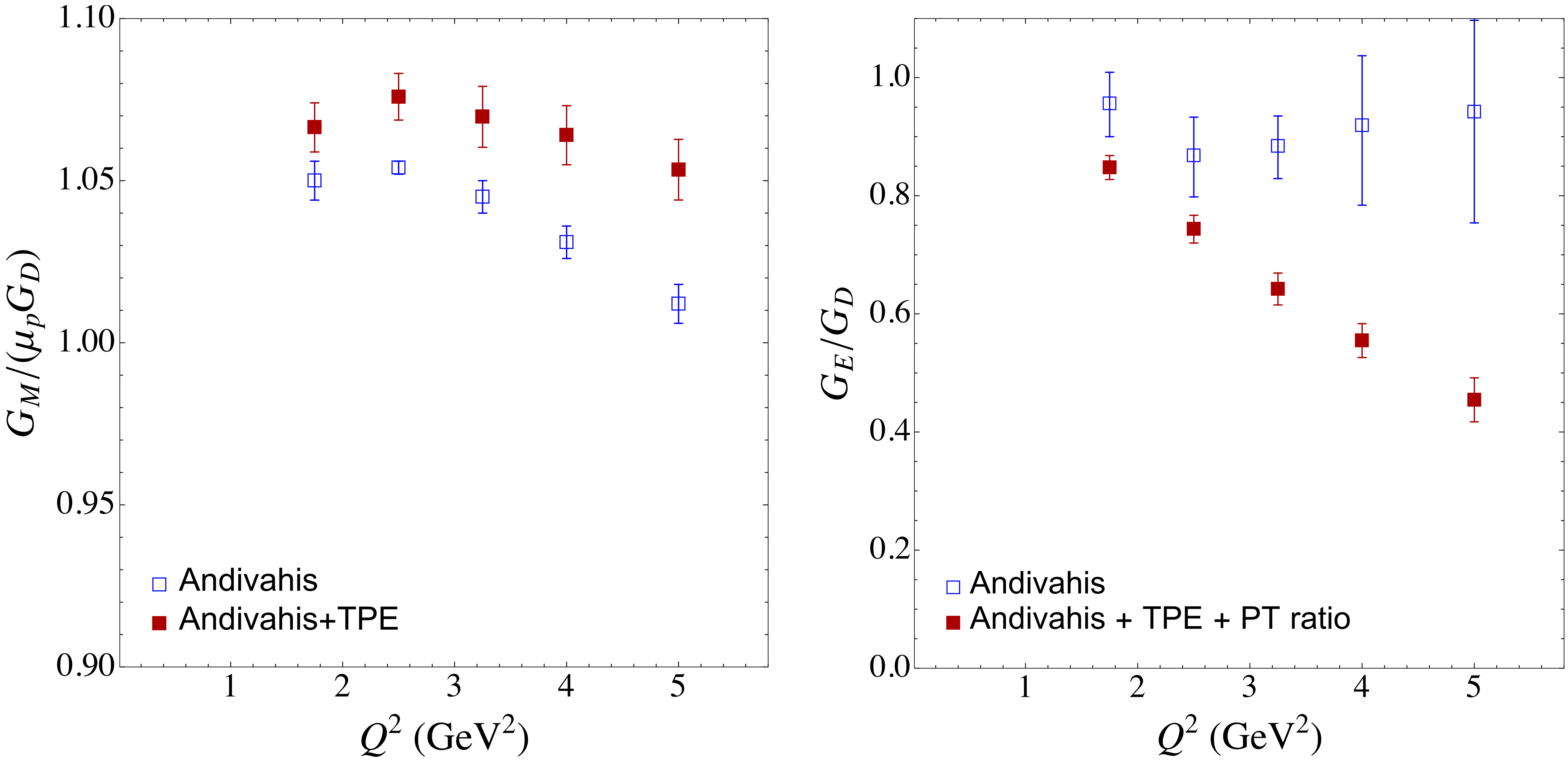
- Example from Andivahis data set at $Q^2 = 4\ \mathrm{GeV}^2$
- Uses improved RC + our TPE
- No evidence of non-linearity

Proton form factor ratio: Rosenbluth



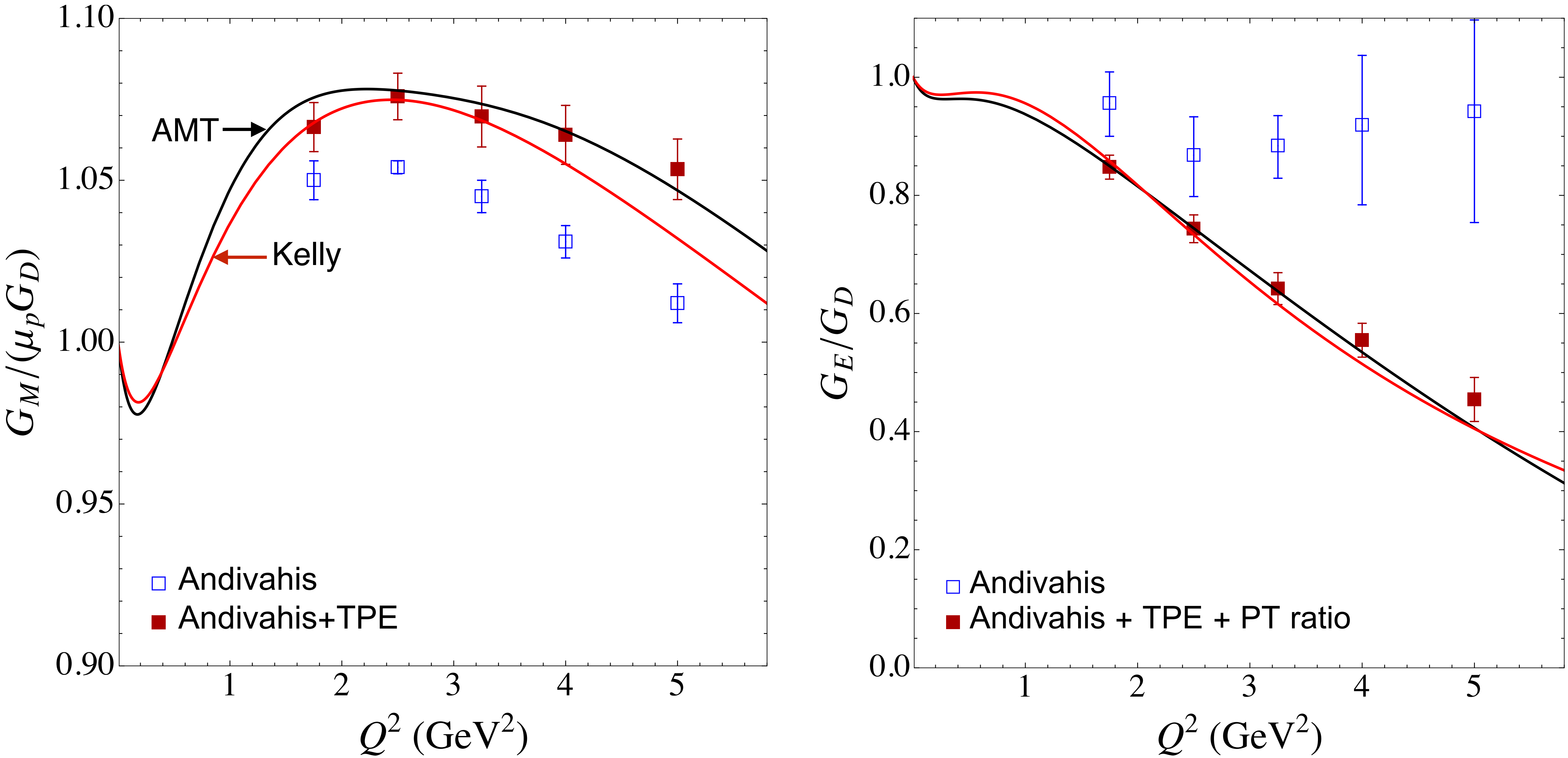
- For Super Rosenbluth use $\delta_{\mathrm{RC}} = \delta(\mathrm{MTj}) - \delta(\mathrm{MTs})$ plus our TPE

Magnetic and Electric form factors



- For G_E, use G_M and PT ratio (G_E/G_M)

Magnetic and Electric form factors



- For G_E, use G_M and PT ratio (G_E/G_M)
- Kelly (2004) and AMT (2007) parameterizations accounting for TPE (as known at the time)

Summary

- $N(1520)3/2^-$ is the major contributor for higher Q^2
- Elastic nucleon alone is a good approximation for $Q^2 < 1\ \mathrm{GeV}^2$
- Overall enhancement in the TPE cross section correction at $Q^2 > 3\ \mathrm{GeV}^2$
- Width effect is negligible
- Proper inclusion of TPE resolves $\mu_p G_E/G_M$ discrepancy
- Need more data in the higher Q^2 region
- Follow up work: inclusion of non-resonant background and spin $5/2$ resonances.

Thanks !