Strangeness content of the nucleon: Theory overview

Ross Young

Jefferson Lab
THOMAS JEFFERSON NATIONAL ACCELERATOR FACILITY

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Outline

- Motivating the search for strangeness
- PVES and strange vector form factors
- Contamination from axial ff
- Lattice-inspired predictions for GMs & GEs
- Dramatic advances in PVES data

Why?

- Strange quarks contribute to nucleon structure!
- No symmetry of QCD can deny them

$$\langle N' | \bar{s} \Gamma s | N \rangle \neq 0$$

- Probing strangeness gives direct information on nonperturbative QCD
  - Quark dynamics distinguish the real world from pure Yang-Mills theory

Why strange?

- Protons/neutrons carry light quarks
  - Source of nonperturbative glue
    AND part of nonperturbative glue
- Strange quarks are ONLY in the glue

Strange Vector FFs

- Parity-violating electron scattering (PVES)
- Interference between γ and Z probes

$$A^{PV} = \frac{\sigma_R - \sigma_L}{\sigma_R + \sigma_L} = \left[\frac{-G_F Q^2}{\pi\alpha\sqrt{2}}\right] \frac{\varepsilon G_E^{p\gamma} G_E^{pZ} + \tau G_M^{p\gamma} G_M^{pZ} - \frac{1}{2}(1-4\sin^2\theta_W)\varepsilon' G_M^{p\gamma} \tilde{G}_A^p}{\varepsilon (G_E^{p\gamma})^2 + \tau (G_M^{p\gamma})^2}$$

$$4G_{E,M}^{pZ} = (1-4\sin^2\theta_W) G_{E,M}^{p\gamma} - G_{E,M}^{n\gamma} - G_{E,M}^{s}$$

Strangeness

Axial FF in PVES

- At tree level

$$G_A^p = -G_A^{(T=1)} - G_A^{(s)}$$

- Including radiative corrections

$$\tilde{G}_A^p = -(1+R_A^{T=1})G_A^{(T=1)} + R_A^{T=0}G_A^{(8)} - (1+R_A^0)G_A^{(s)} + A_{ana}^p$$

$$G_A^{(T=1)} = 1.2695$$

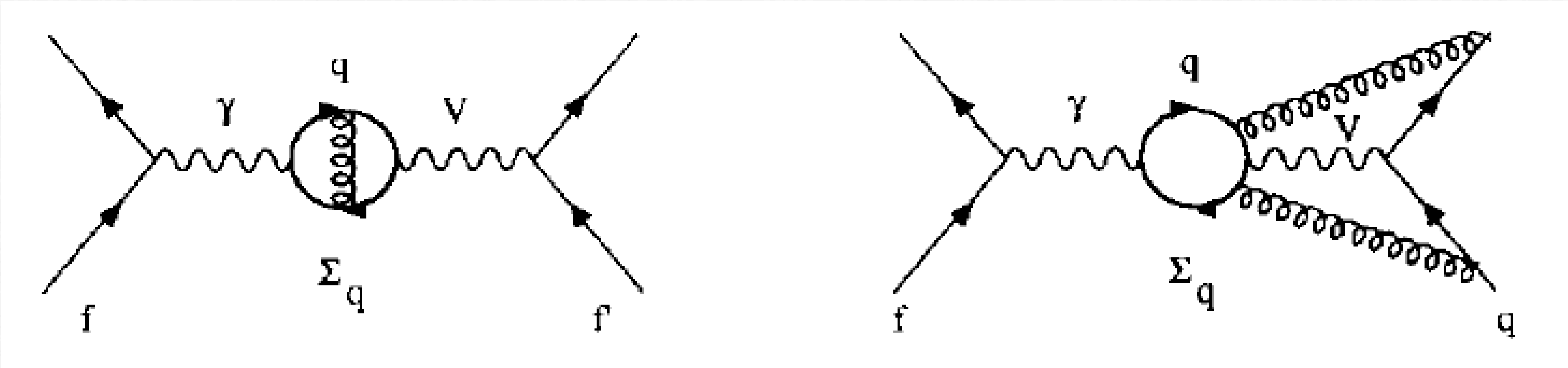
$$G_A^{(8)} = 0.58 \pm 0.03 \pm 0.12$$

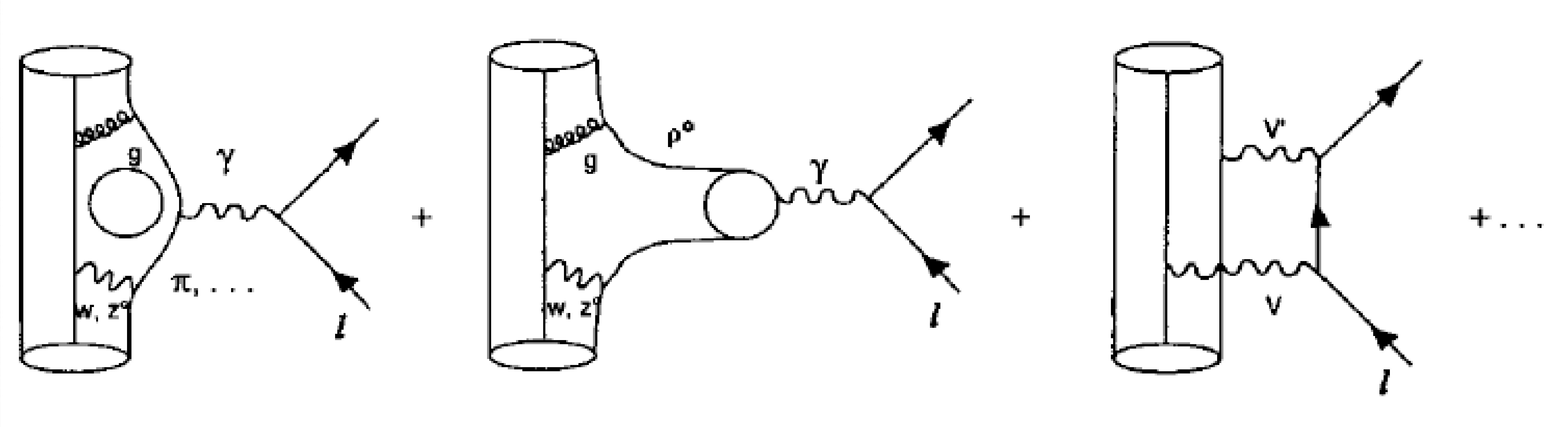
$$G_A^{(s)} = -0.07 \pm 0.04 \mp 0.05$$

R_A : PDG

"Anapole" term: Nonperturbative hadronic radiative corrections

The Anapole term



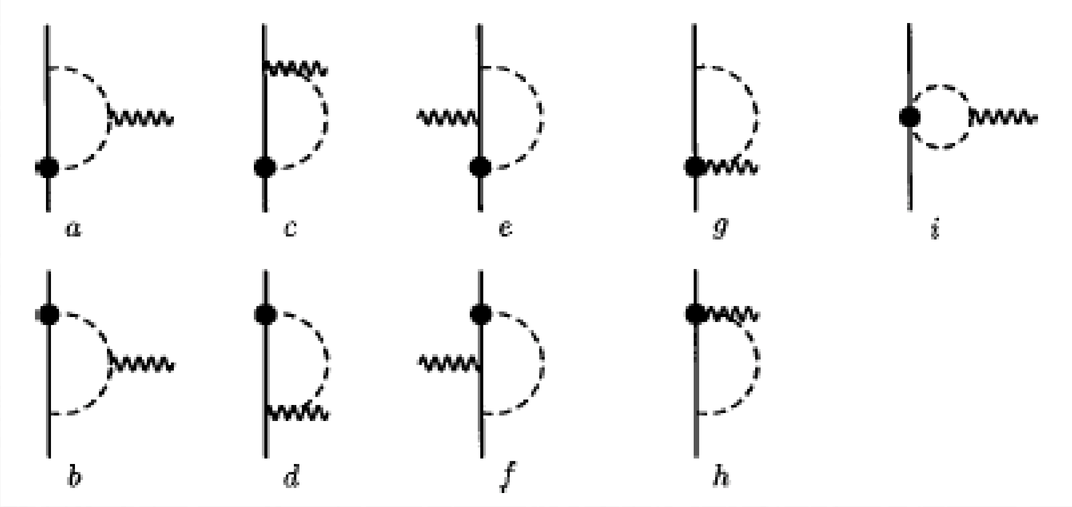


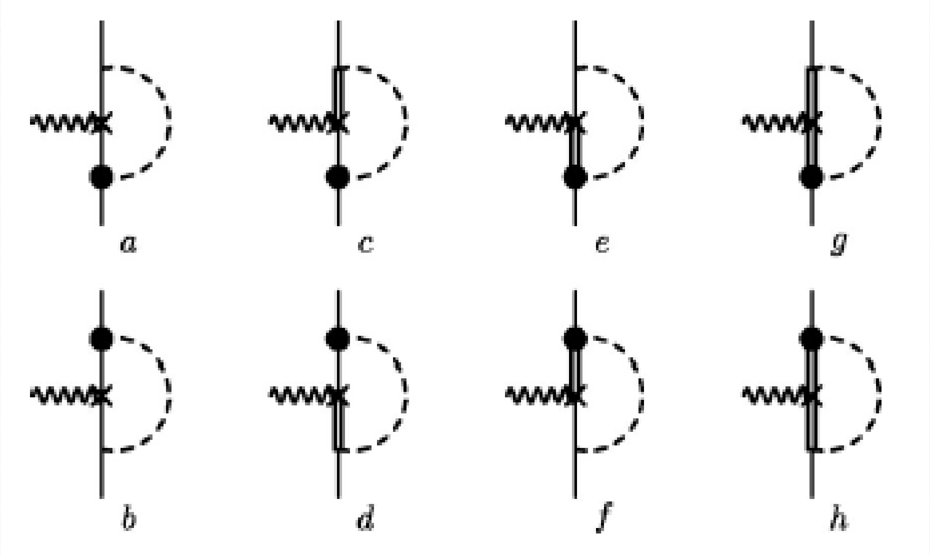
Musolf et al. Phys.Rept.(1994)

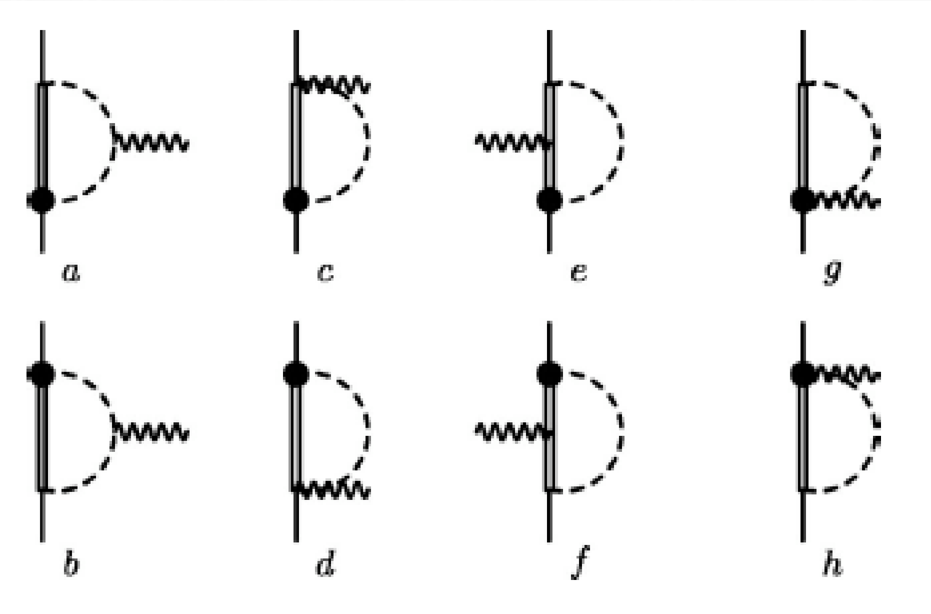
Estimate from EFT

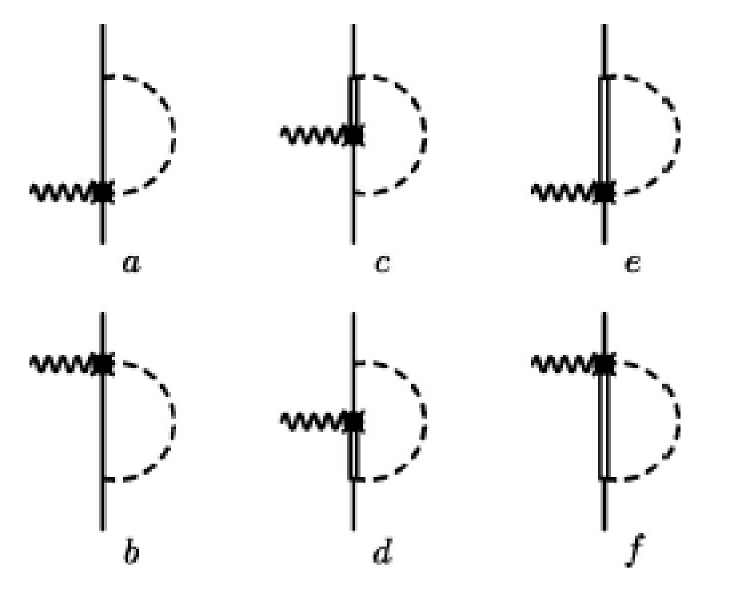
Zhu et al. PRD(2000)

- Build EFT with PV meson-baryon couplings









Summing the result

Zhu et al. PRD(2000)

- Determine chiral-loop contributions
  - Use VMD to constrain LECs
- Best-estimates for poorly-known PV couplings

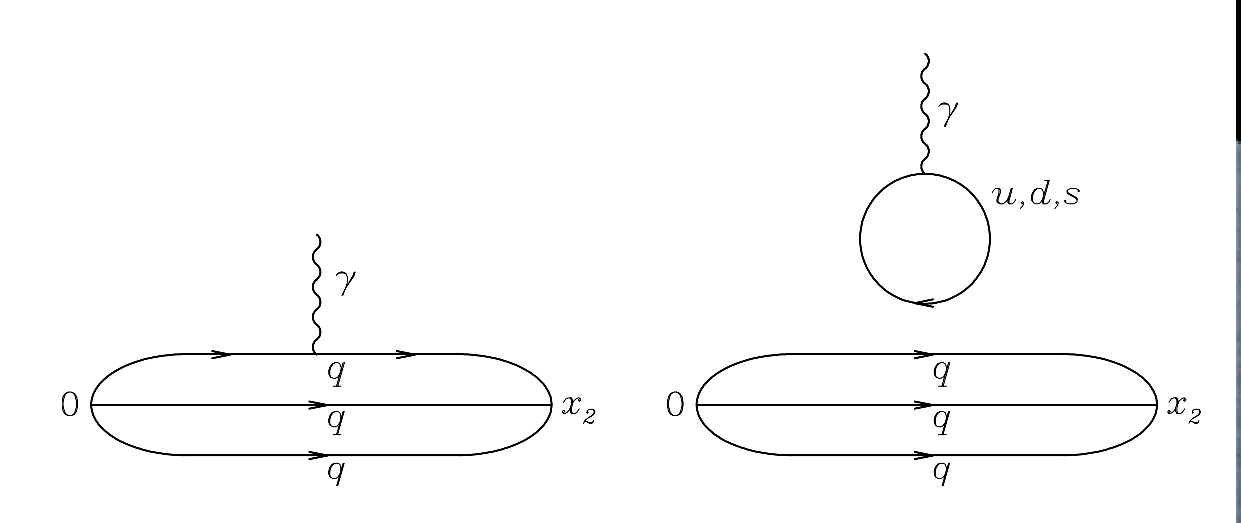
$$h_\pi,\ h_A^1,\ h_{n\Sigma^- K},\ h_V^{n\Sigma^- K^+},\ h_V^{p\Sigma^0 K^+},\ h_A^{pK},\ h_A^{nK}$$
$$h_{p\Lambda K},\ h_V^{p\Lambda K^+},\ h_\rho^1,\ h_\omega^0,\ h_\phi^0$$
$$h_A^2,\ h_V^0,\ h_V^2,\ h_\rho^0,\ h_\rho^2,\ h_\omega^1,\ h_\phi^1$$

$$A_{ana}^{T=1} = -0.11 \pm 0.44 \qquad A_{ana}^{T=0} = 0.02 \pm 0.26$$

Strange FFs

- Lattice-inspired theory calculation
  - Leinweber, RDY et al. PRL(2005), hep-lat/0601025
- Charge symmetry constraints
  - see Kubis & Lewis, nucl-th/0605006
- Quenched lattice simulation results
- Quantitative unquenching procedure

Charge Symmetry



$$p = \frac{2}{3}u^p - \frac{1}{3}u^n + O_N$$

$$n = -\frac{1}{3}u^p + \frac{2}{3}u^n + O_N$$

$$3O_N = 2p + n - u^p$$

$$\Sigma^+ = \frac{2}{3}u^\Sigma - \frac{1}{3}s^\Sigma + O_\Sigma$$

$$\Sigma^- = -\frac{1}{3}u^\Sigma - \frac{1}{3}s^\Sigma + O_\Sigma$$

$$\Sigma^+ - \Sigma^- = u^\Sigma$$

$$3O_N = 2p + n - \frac{u^p}{u^\Sigma}(\Sigma^+ - \Sigma^-)$$

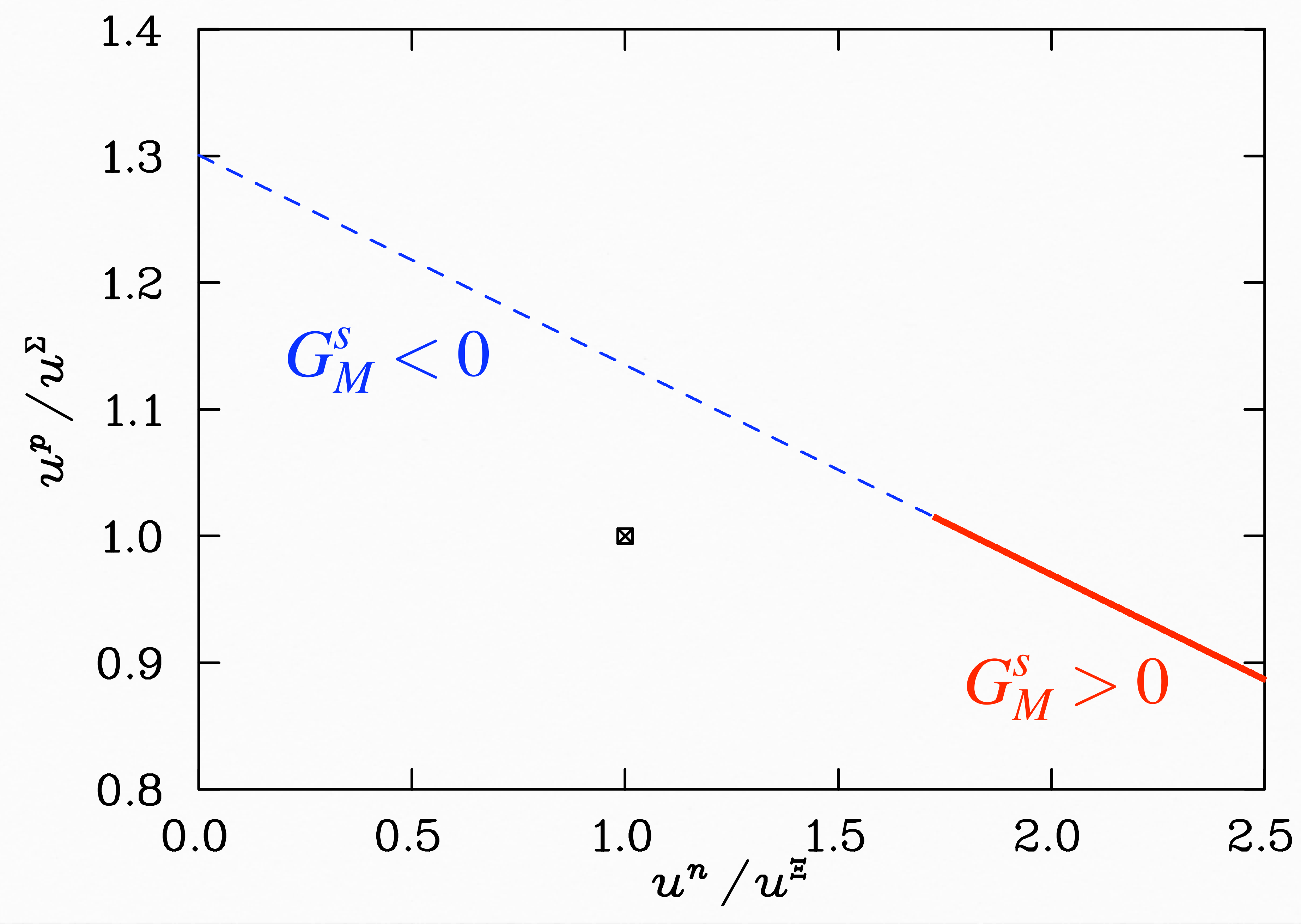
Lattice QCD

$$3O_N = p + 2n - u^n$$

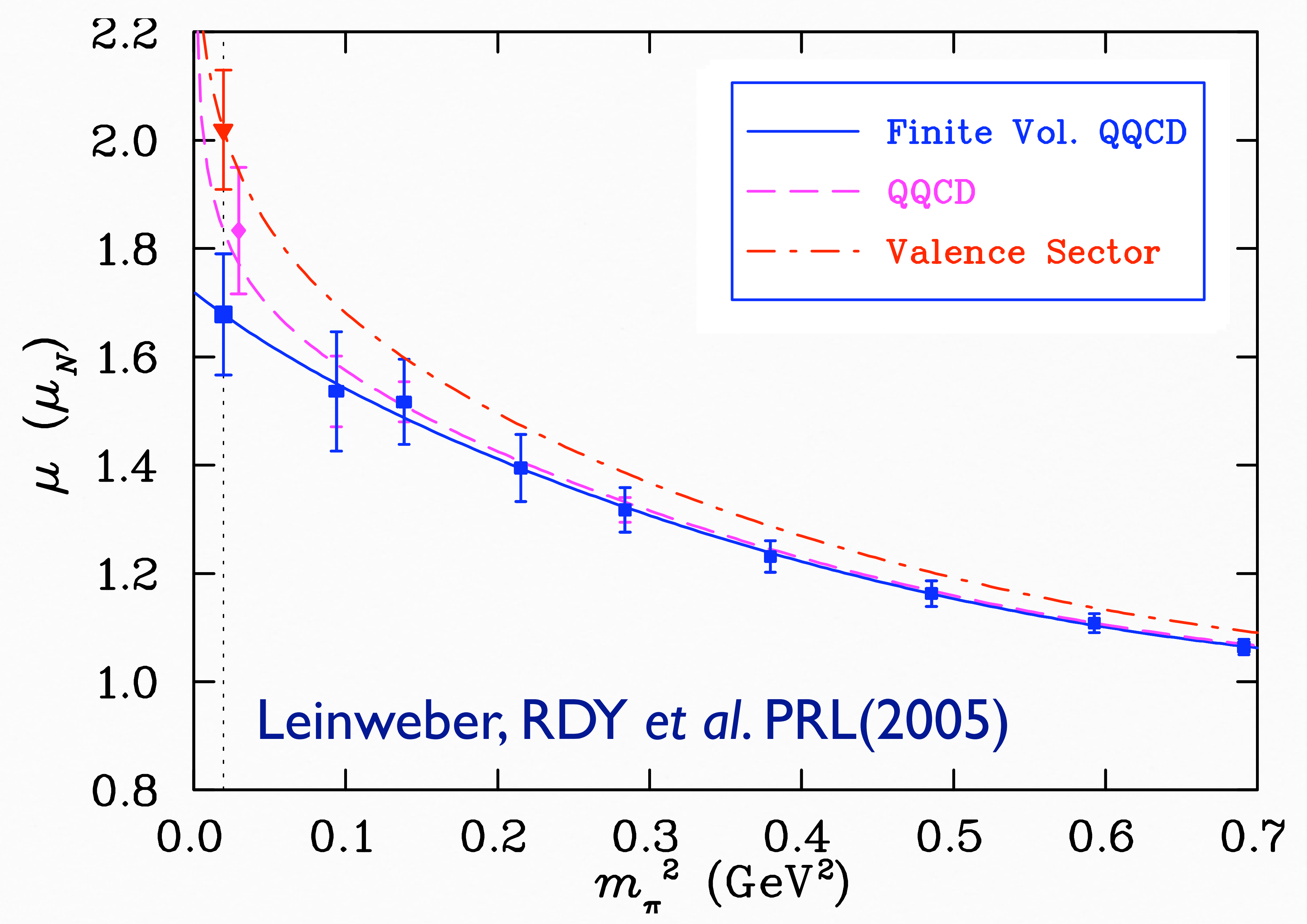
$$\Xi^0 - \Xi^- = u^\Xi$$

$$3O_N = p + 2n - \frac{u^n}{u^\Xi}(\Xi^0 - \Xi^-)$$

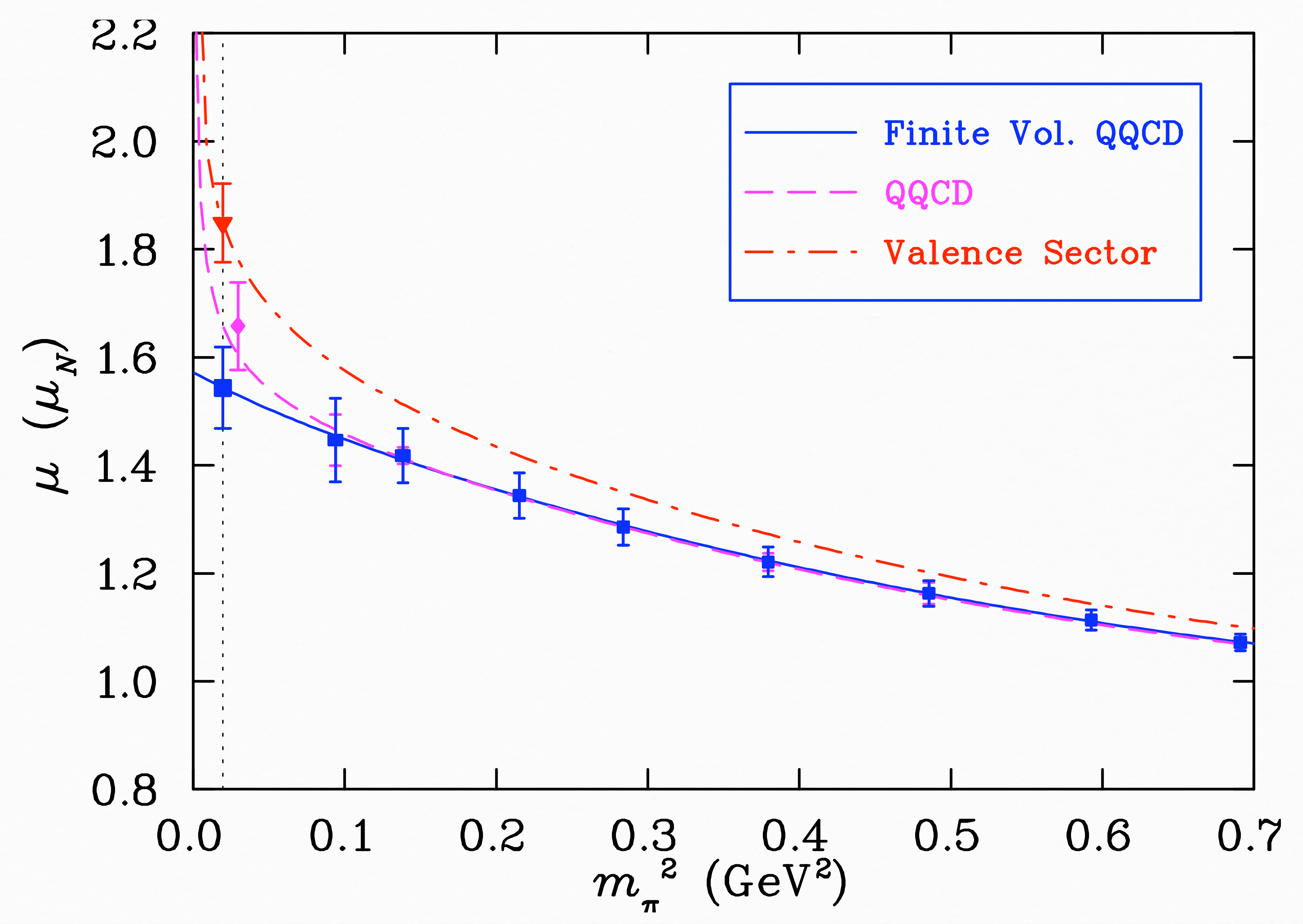
Constraint on GMs



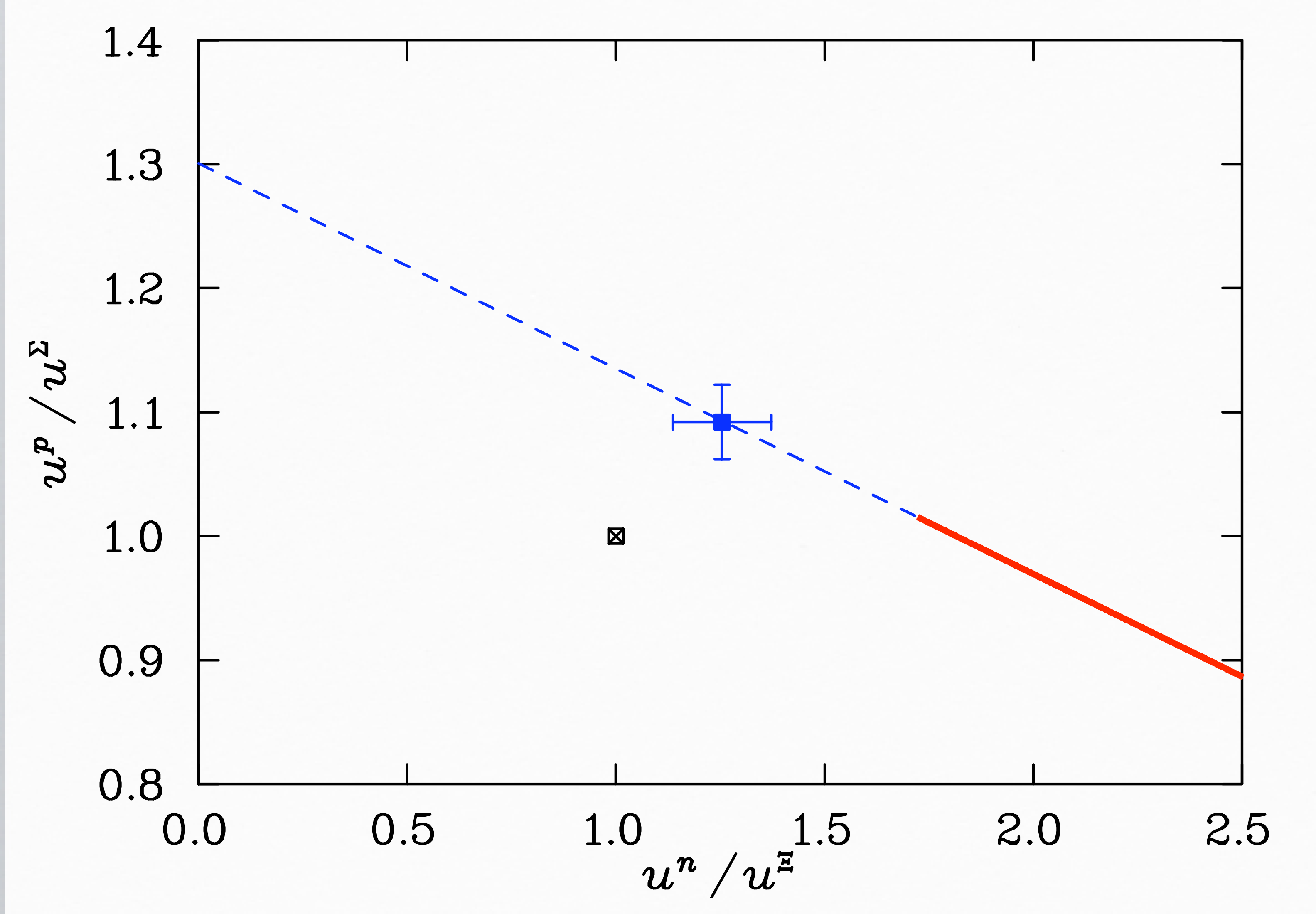
u-quark in proton



u-quark in Sigma



Final Result

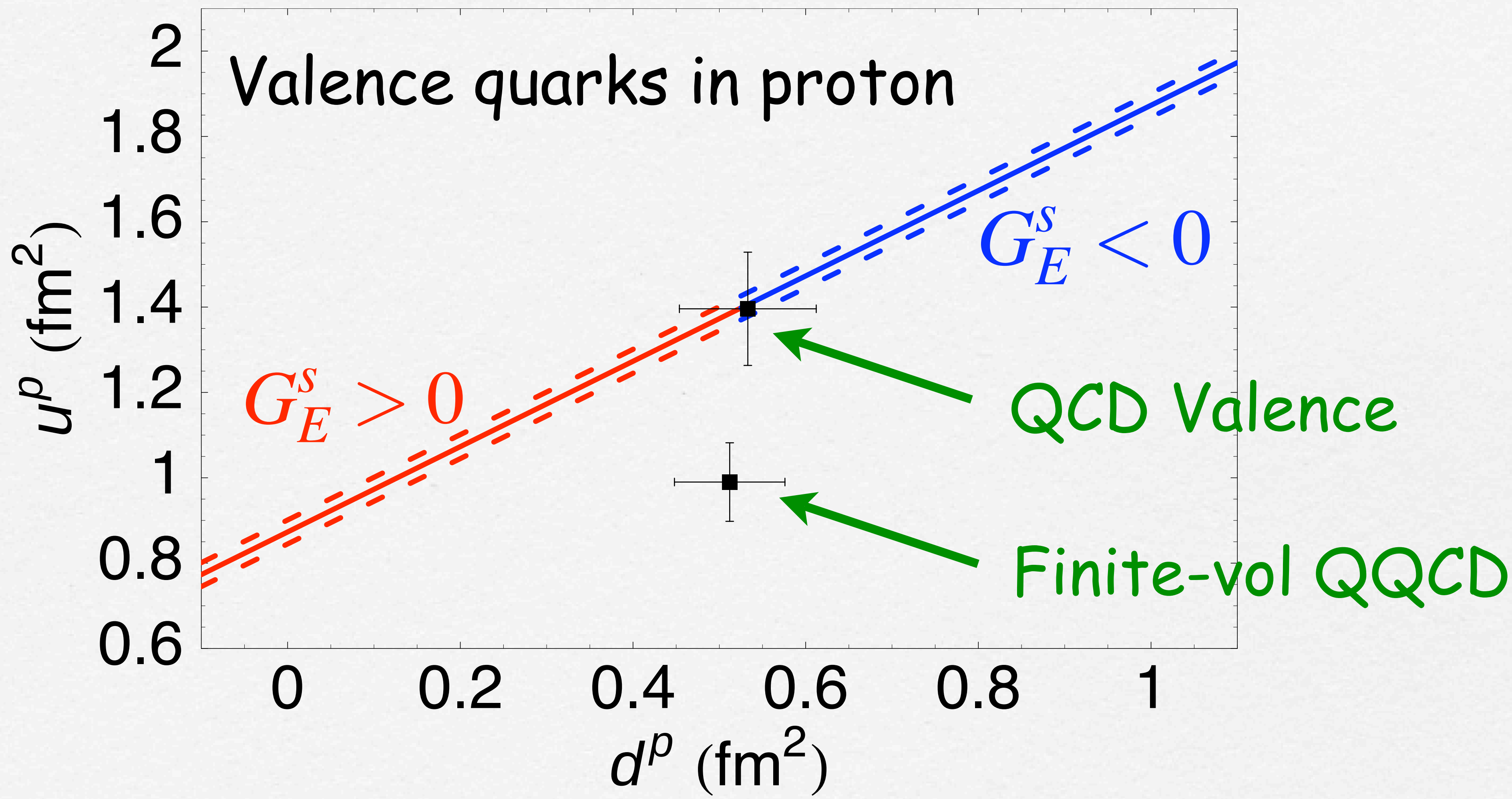


$$\frac{u^p}{u^\Sigma} = 1.092 \pm 0.030$$

$$\frac{u^n}{u^\Xi} = 1.254 \pm 0.124$$

$$G_M^s = -0.046 \pm 0.22\, \mu_N$$

Repeat for electric



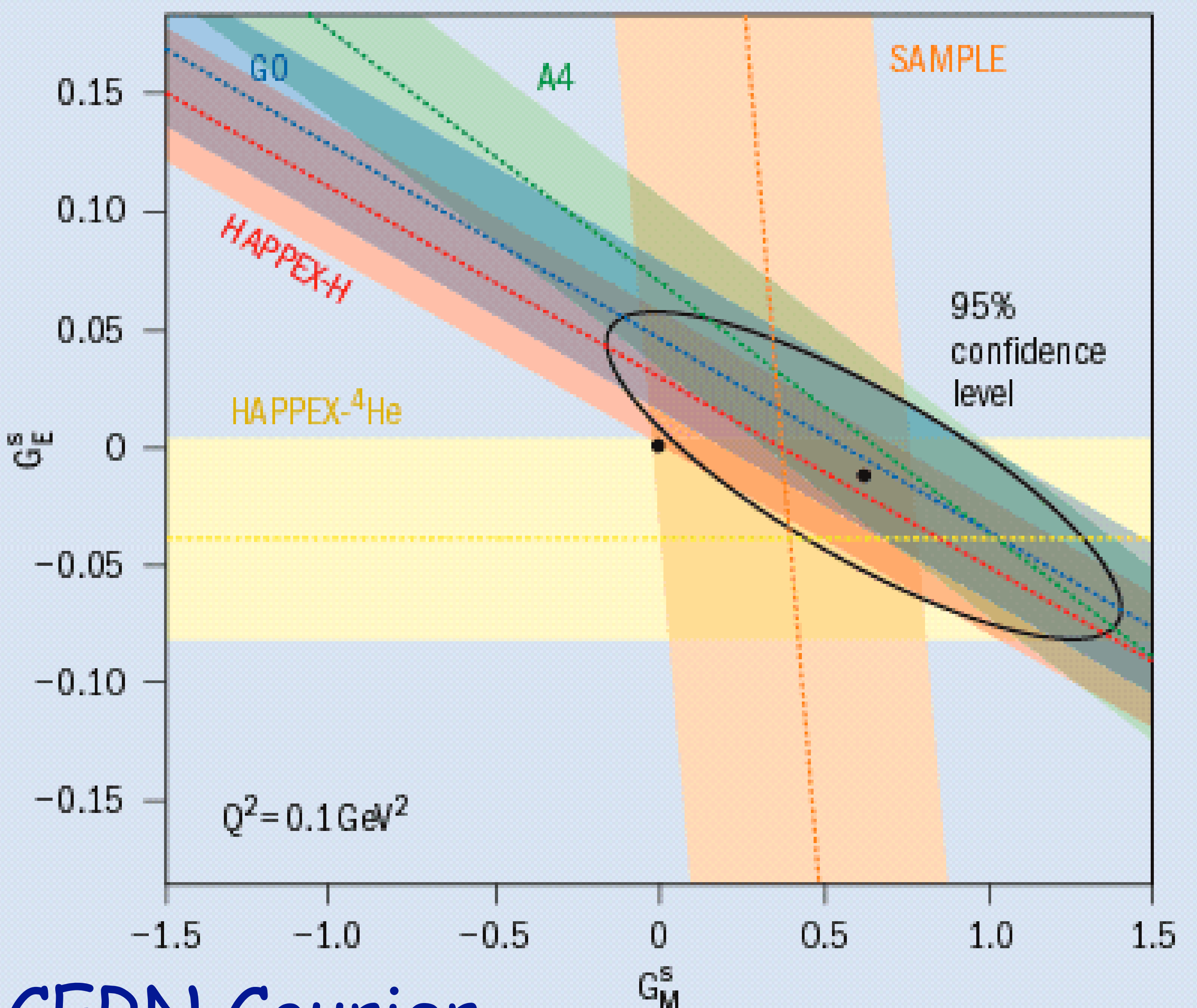
$$G_E^s(Q^2 = 0.1) = +0.001 \pm 0.004 \pm 0.004$$

Leinweber, RDY *et al.* hep-lat/0601025

Experimental Status

- World PVES data, with Axial theory result

$$Q^2 = 0.1\,\text{GeV}^2$$



CERN Courier

Global Analysis

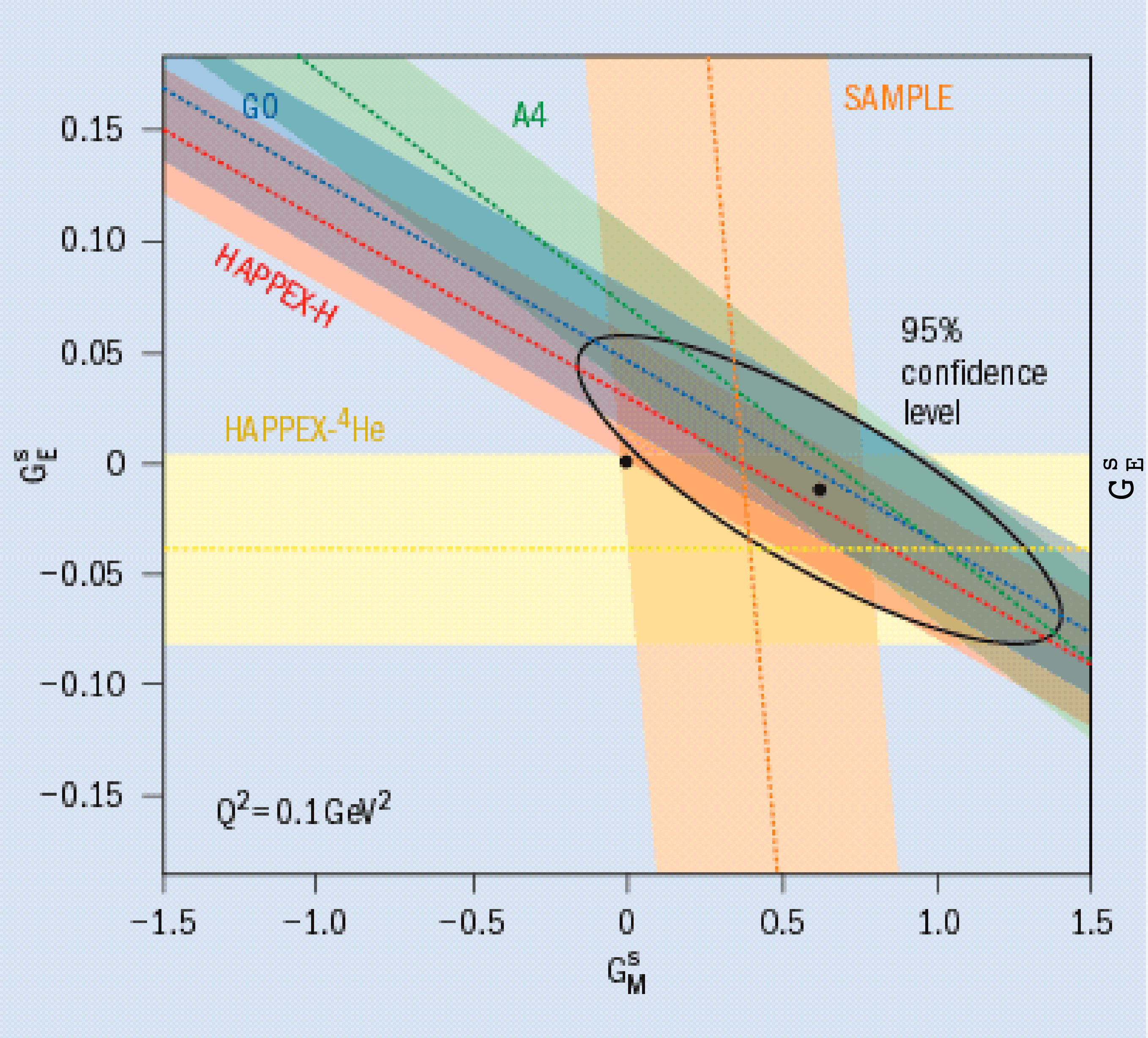
RDY *et al.* nucl-ex/0604010

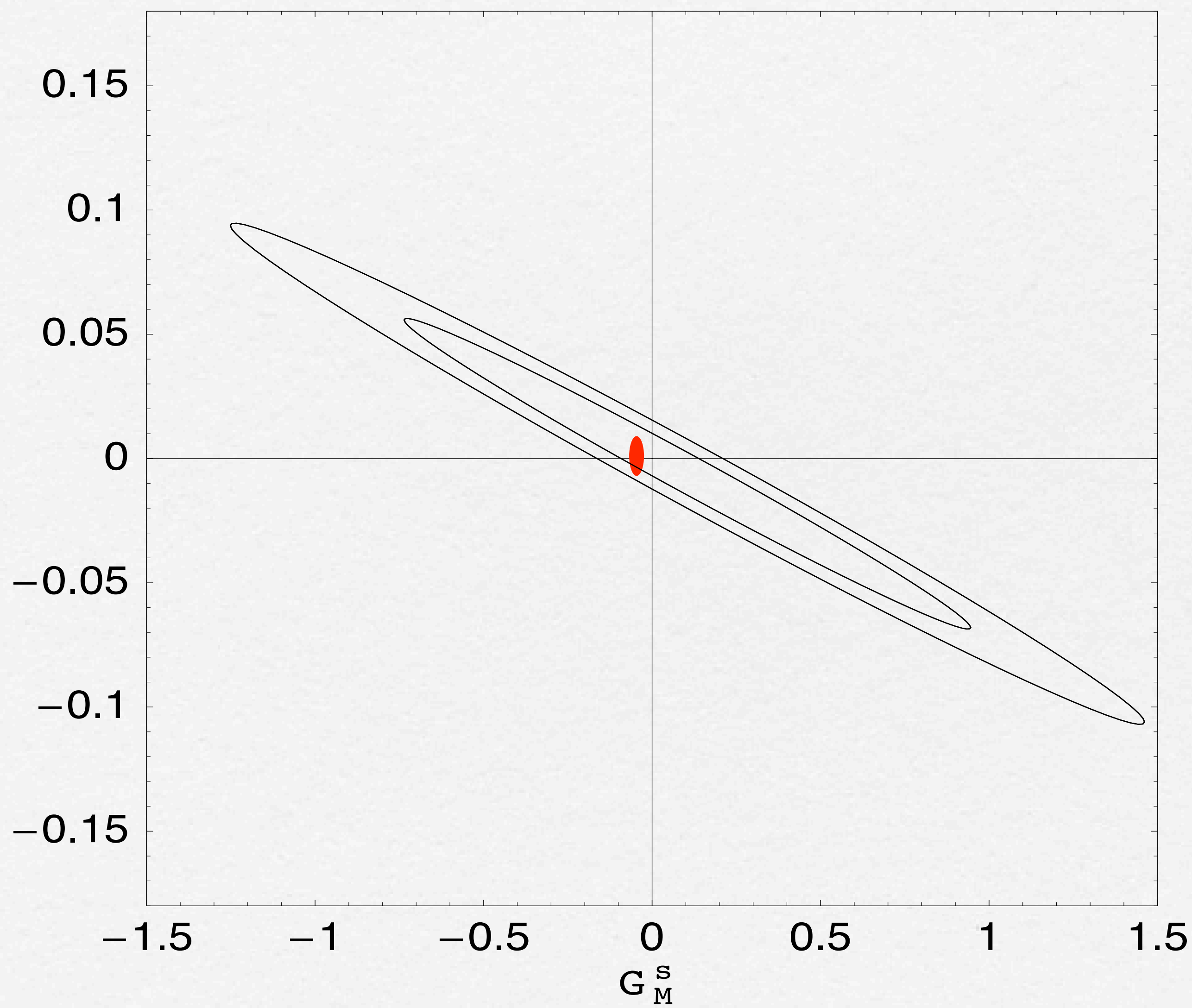
- All data for $Q^2 < 0.3\,\mathrm{GeV}^2$
- Extract axial ff (anapole moment)

$$\tilde{G}_A^N = \tilde{g}_A^N (1 + Q^2/\Lambda^2)^{-2}$$

$$G_E^s = \rho_s Q^2 + \rho_s' Q^4 + \ldots$$
$$G_M^s = \mu_s + \mu_s' Q^2 + \ldots$$

GMs–GEs

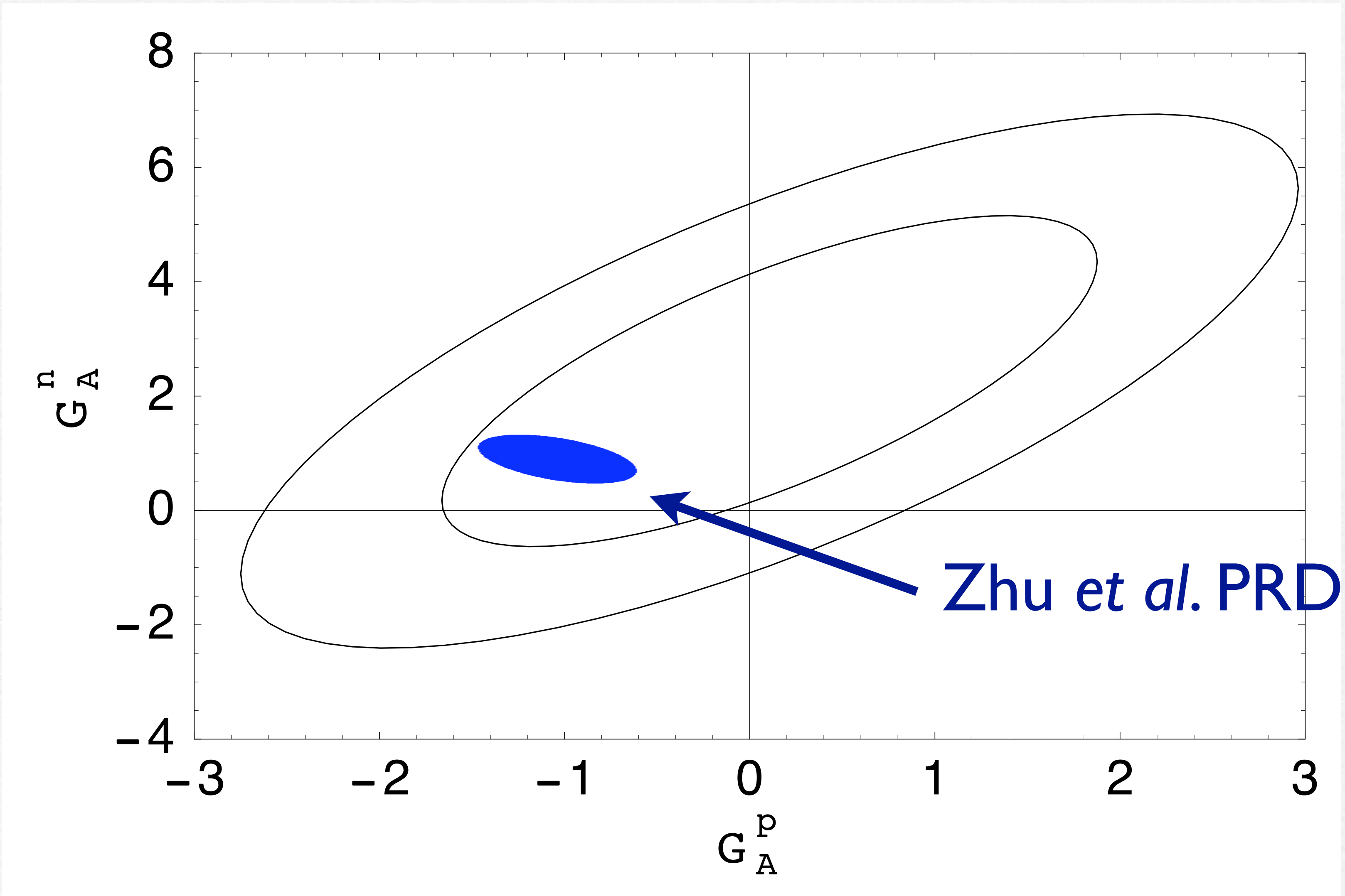




RDY *et al.* nucl-ex/0604010

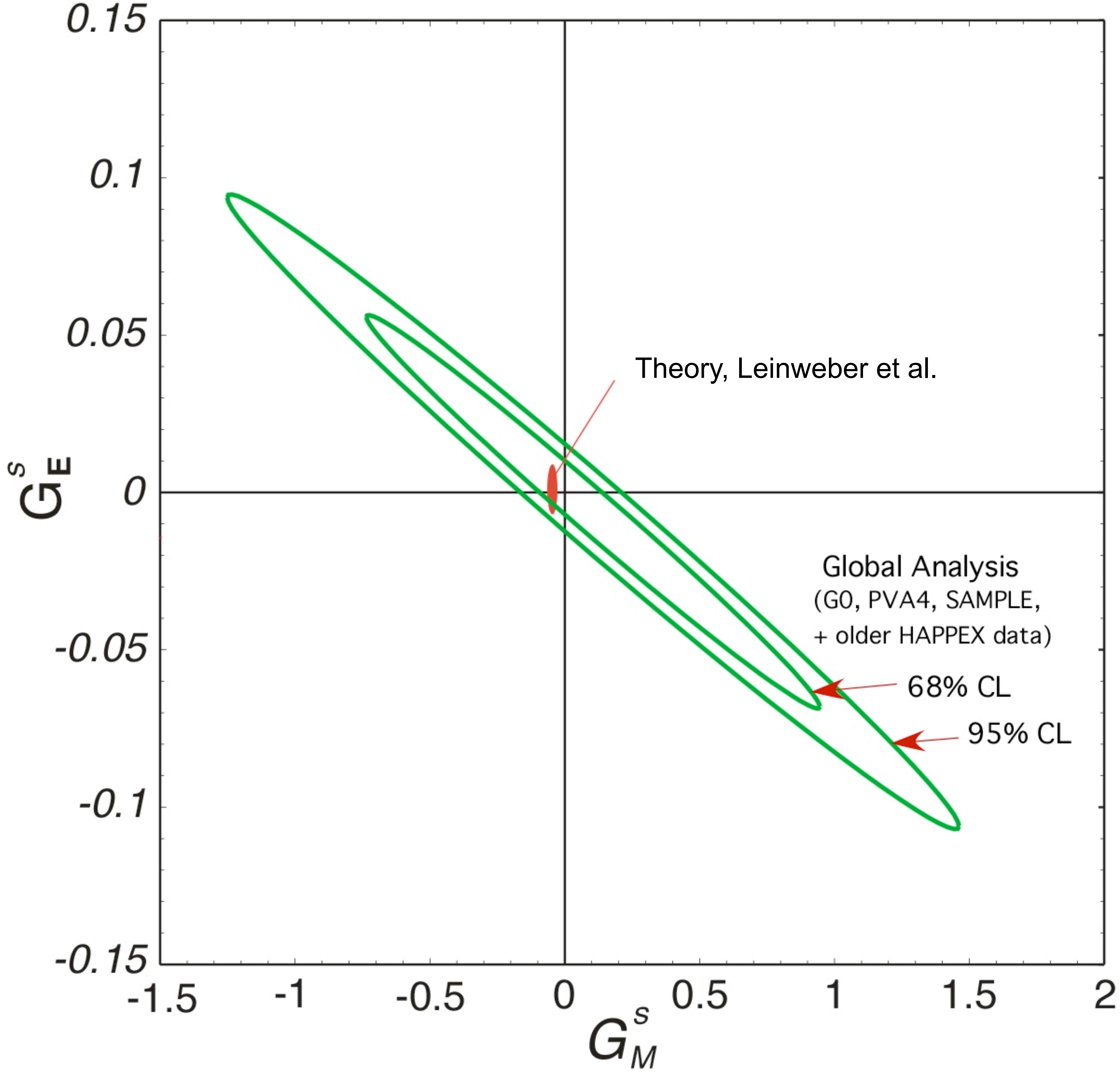
Axial FF

RDY *et al.* nucl-ex/0604010

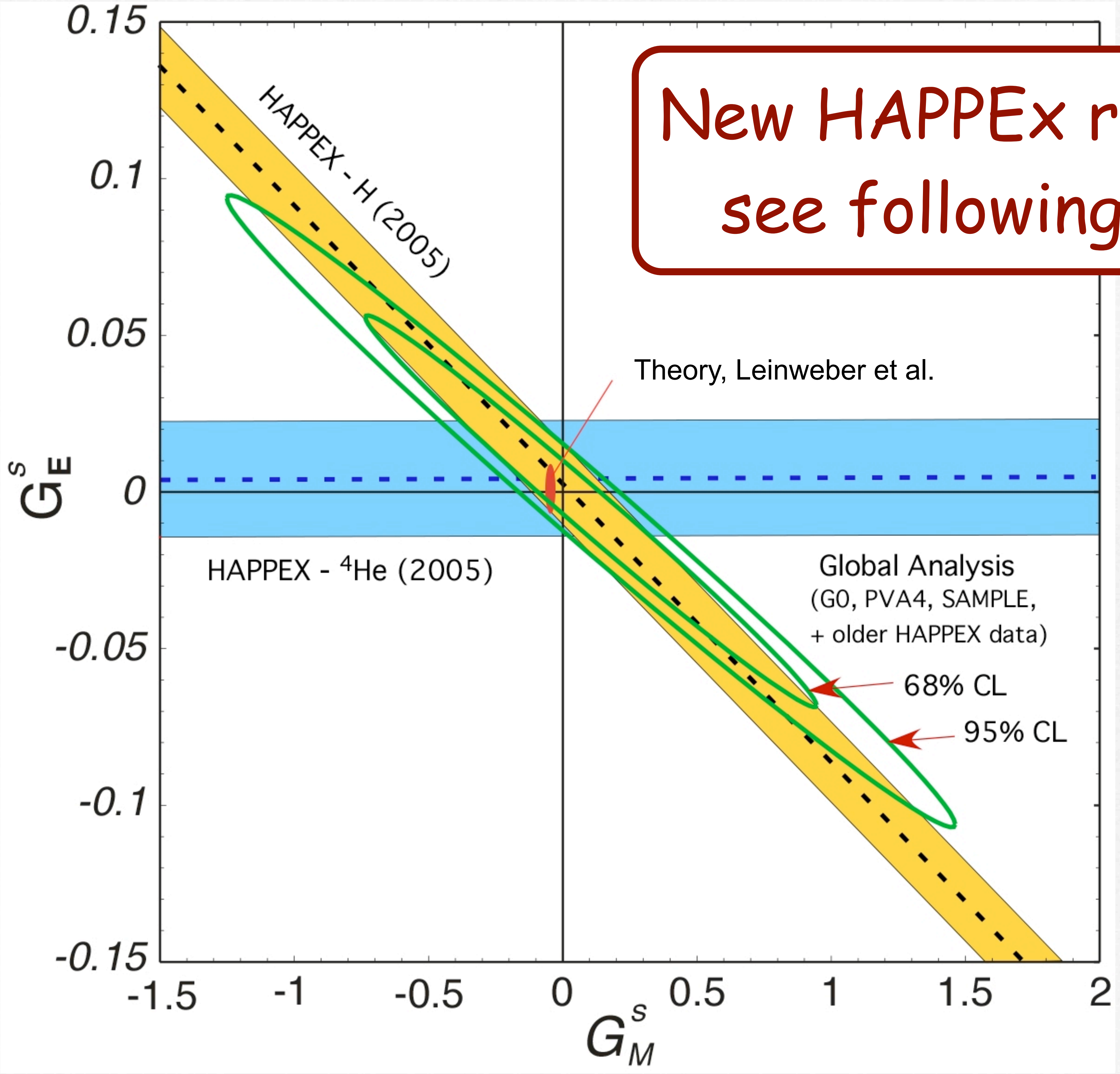


Isoscalar anapole term potentially large:

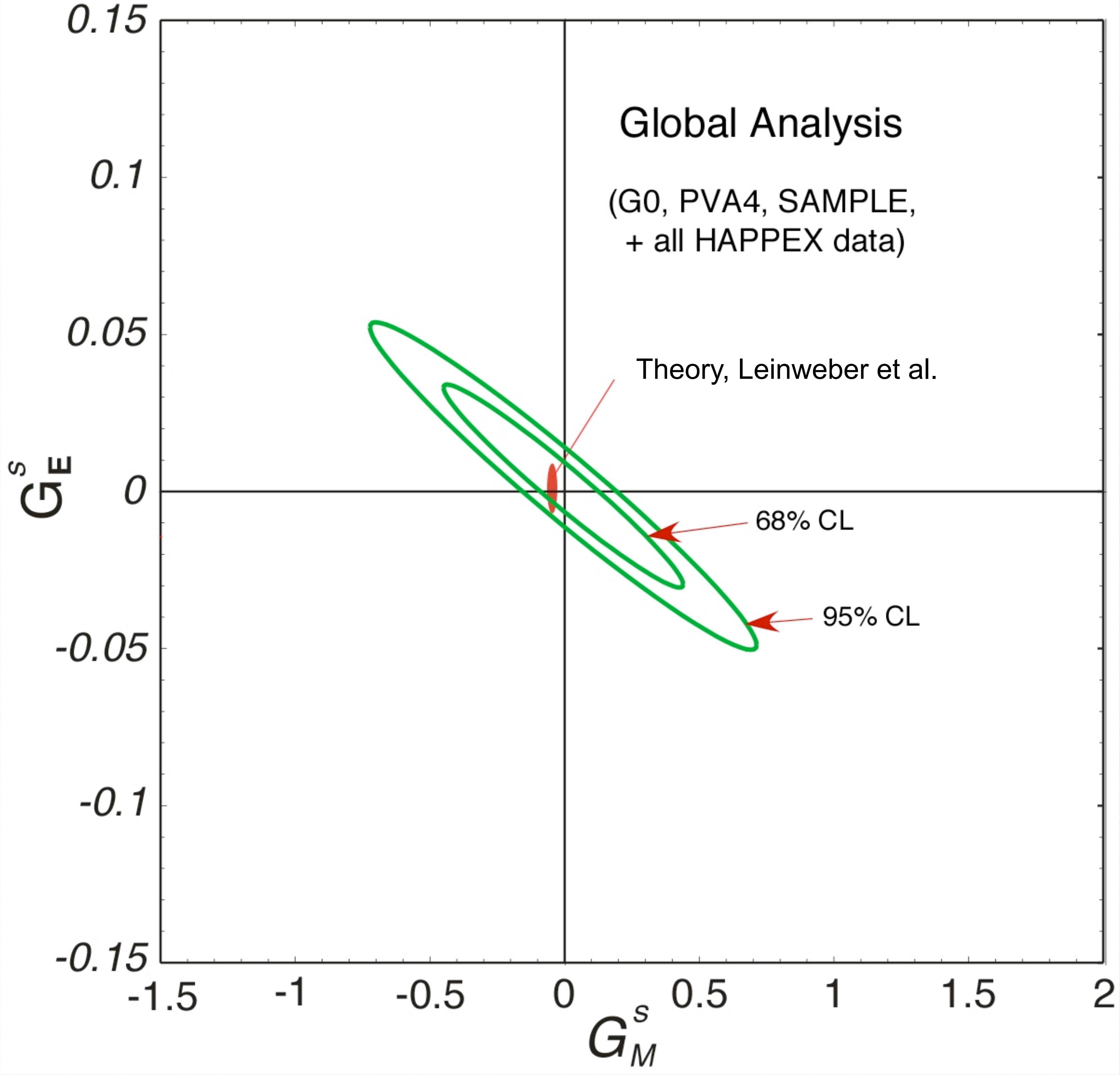
Large uncertainty



0.15
0.1
0.05
0
-0.05
-0.1
-0.15
-1.5
-1
-0.5
0
0.5
1
1.5
2
G_E^s
G_M^s
Theory, Leinweber et al.
Global Analysis
(G0, PVA4, SAMPLE,
+ older HAPPEX data)
68% CL
95% CL



New HAPPEx results: see following talk



Global Analysis
(G0, PVA4, SAMPLE,
+ all HAPPEX data)
Theory, Leinweber et al.
68% CL
95% CL
0.15
0.1
0.05
0
-0.05
-0.1
-0.15
-1.5
-1
-0.5
0
0.5
1
1.5
2
G^s_E
G^s_M

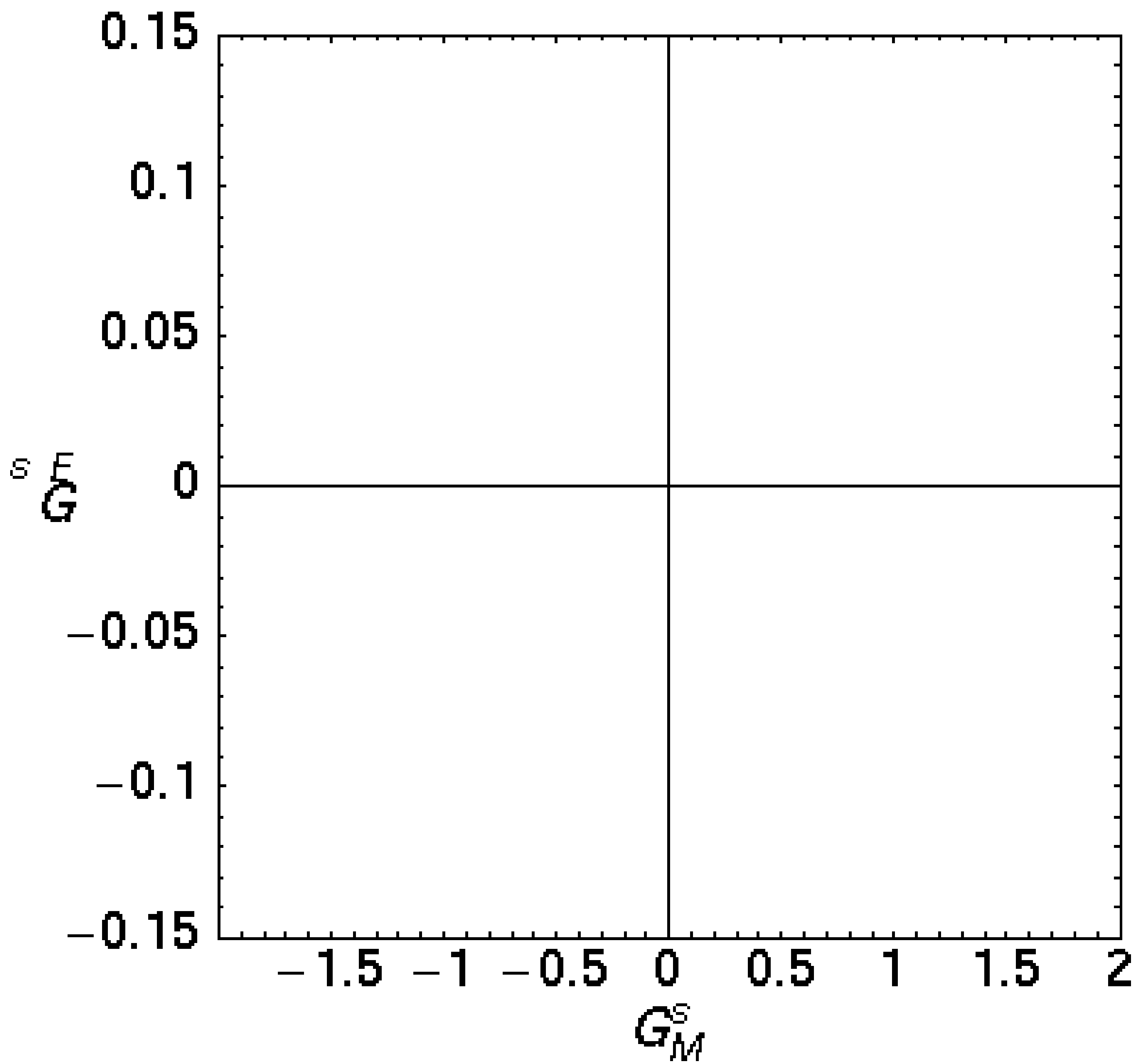
Remarks

- Strangeness in the nucleon fascinating probe of nonperturbative QCD
- New precision in PVES is remarkable

$$\langle r^2 \rangle_E^p = 0.766 \pm 0.012\,\mathrm{fm}^2$$

$$\langle r^2 \rangle_E^s = 0.001 \pm 0.017\,\mathrm{fm}^2$$

- Excellent agreement with state-of-the-art theory calculations
- Advanced understanding of nonpert. QCD



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HAPPEx