Strange Form Factors of the Nucleon

Ross Young

3rd Topical Workshop on Lattice Hadron Physics (LHP06)
Jefferson Lab, 31 July–3 August 2006

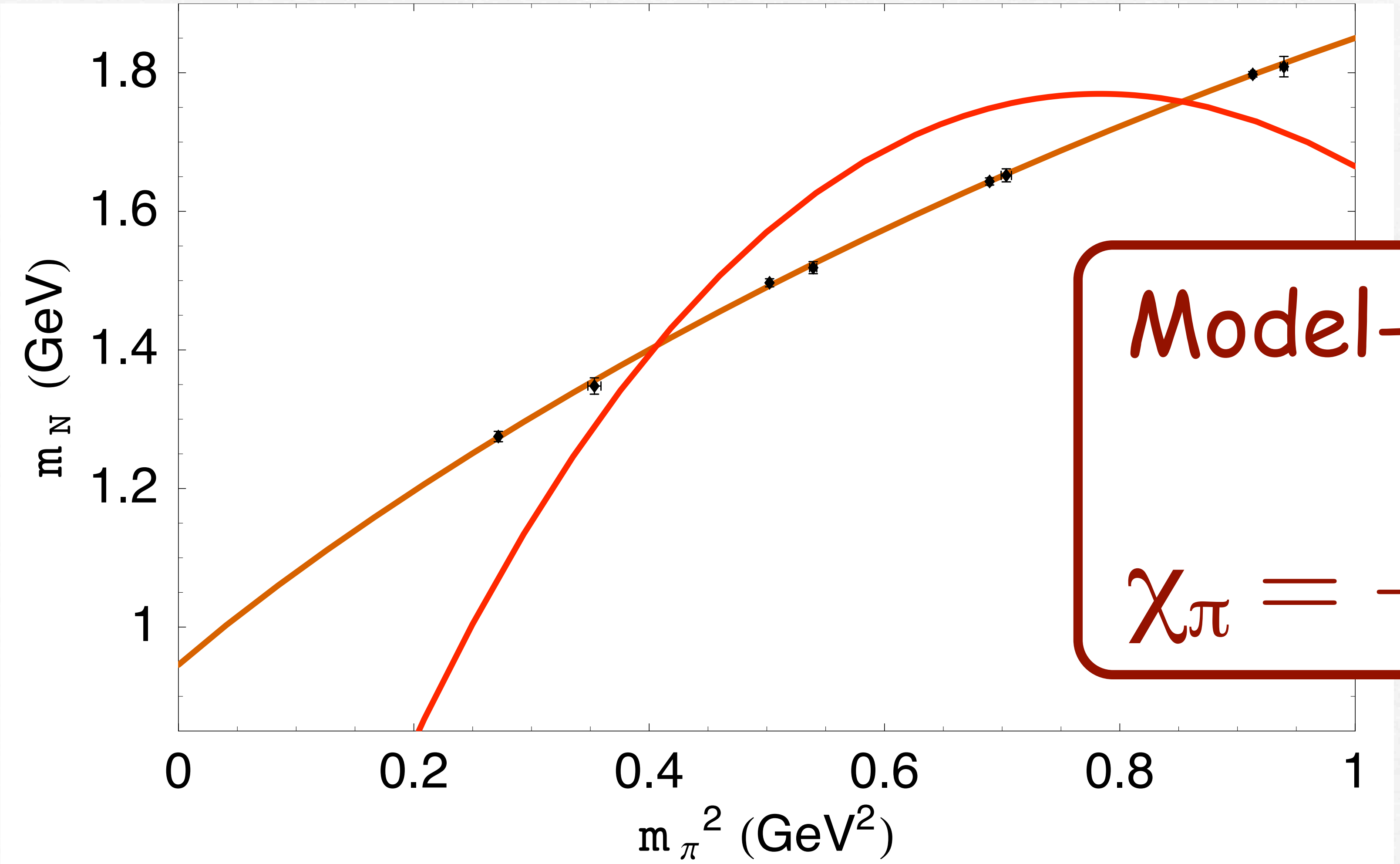
Thomas Jefferson National Accelerator Facility

Outline

- Independent-of-model chiral extrapolations
- Chiral analysis of dynamical quarks in lattice QCD
- Applications in EM form factors
  - Extracting GMs & GEs
- Comparison with latest experimental results

Chiral extrapolation

ChPT: $M_N = c_0 + c_2 m_\pi^2 + \chi_\pi m_\pi^3 + \ldots$

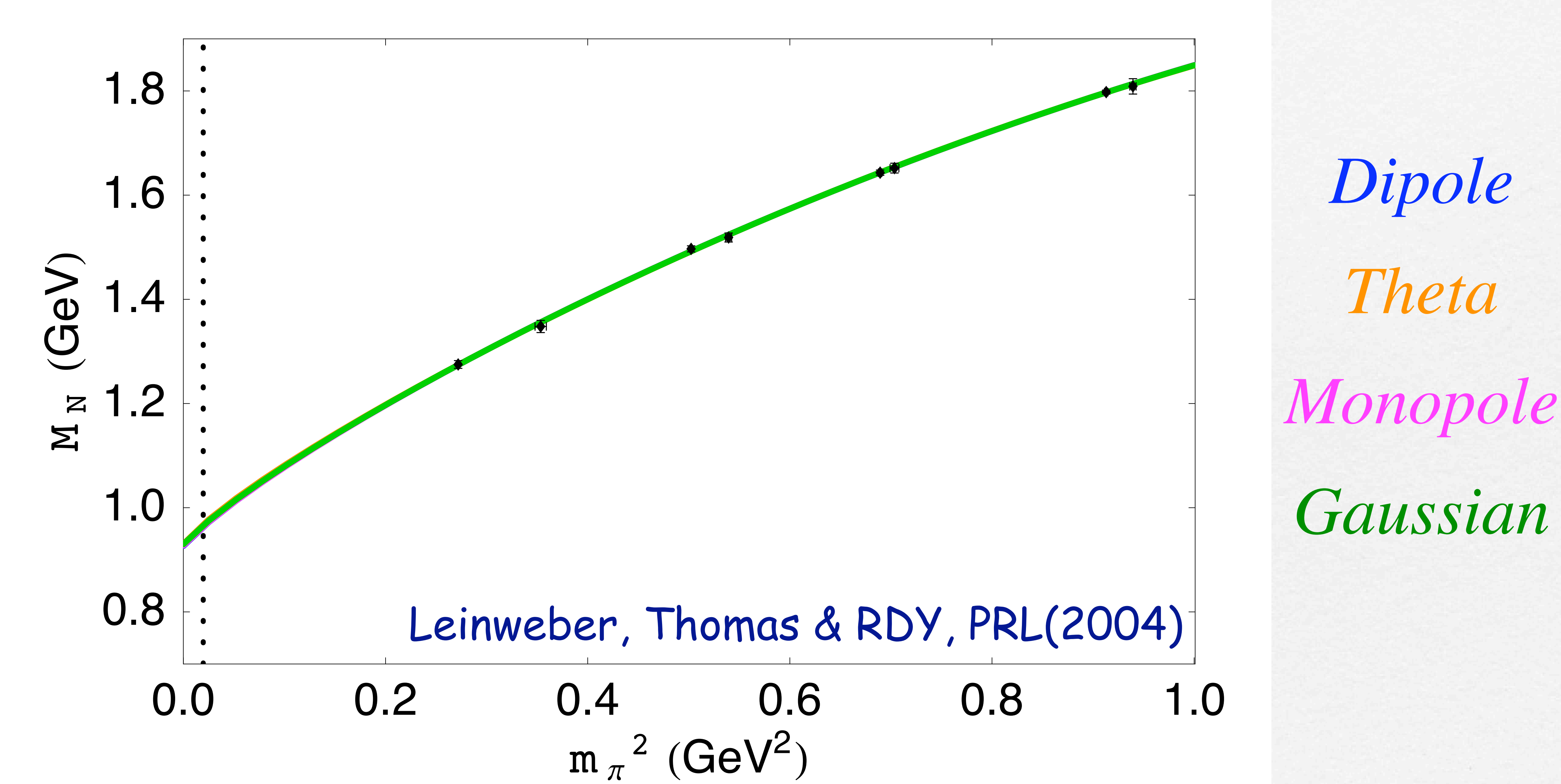


Model-independent value

$\chi_\pi = -5.5\mathrm{GeV}^{-2}$

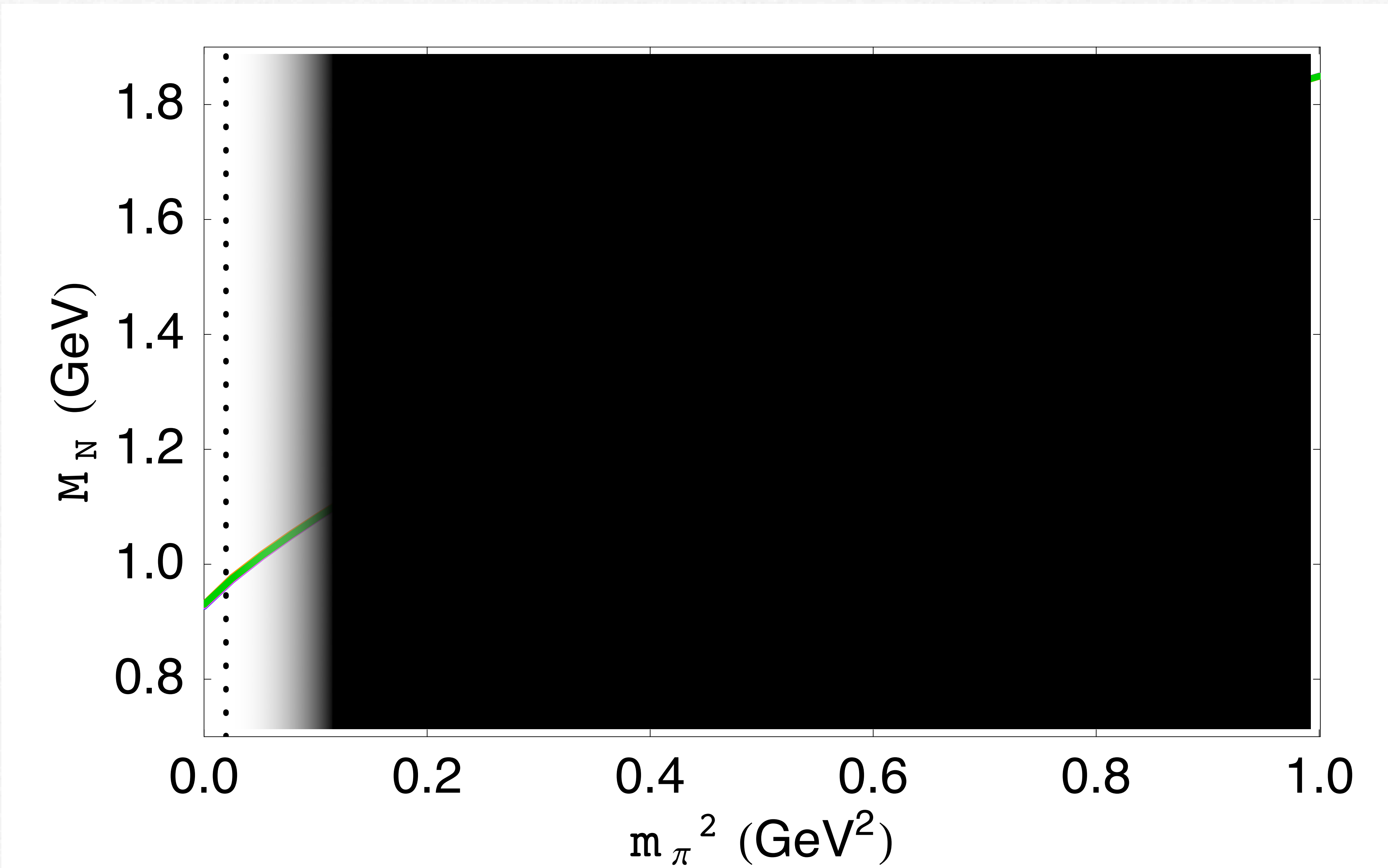
$\chi_\pi \simeq -0.63\mathrm{GeV}^{-2}$

Finite-range regularisation



Independent-of-model chiral extrapolation

Finite-range regularisation



Dipole

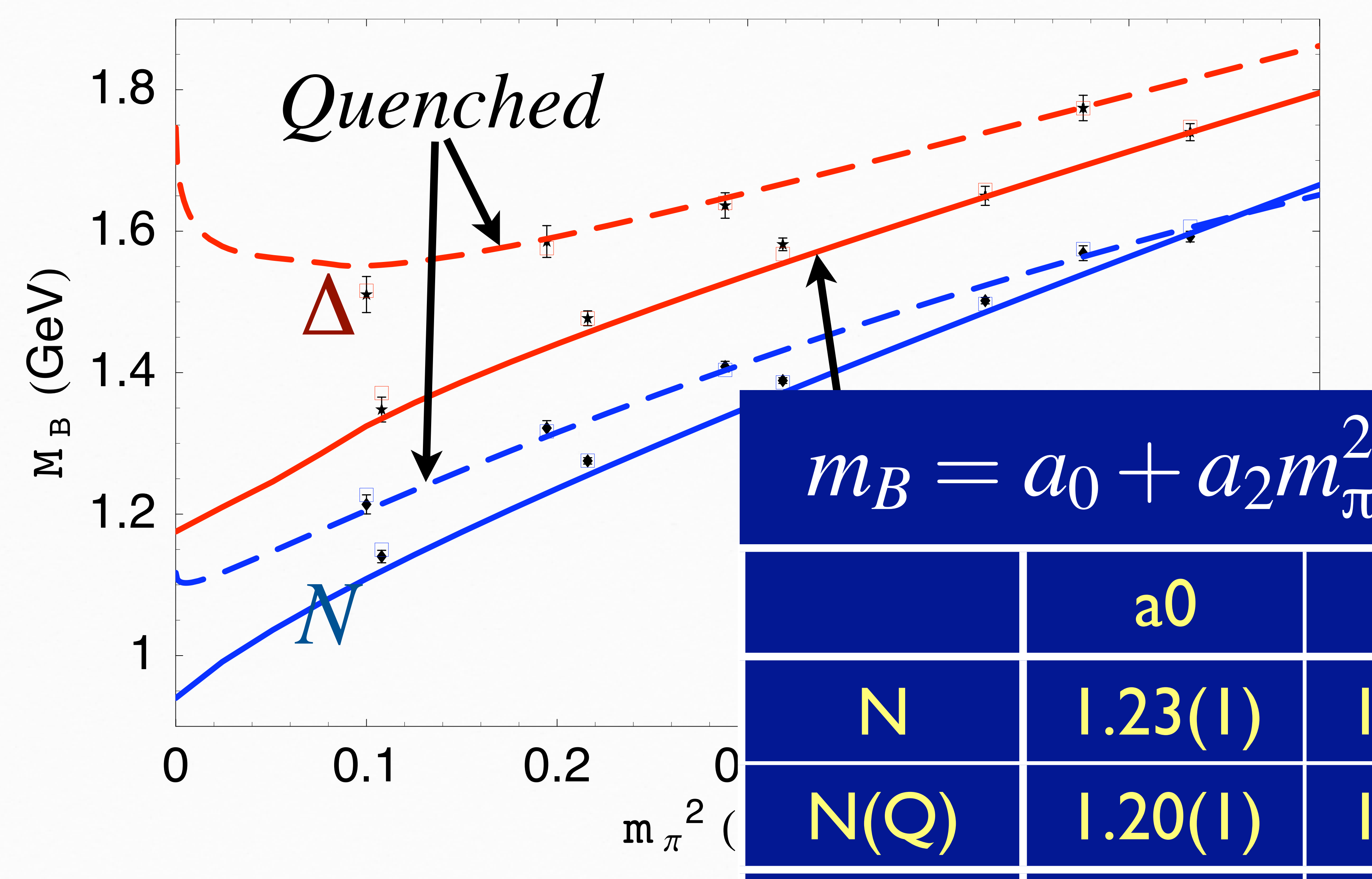
Theta

Monopole

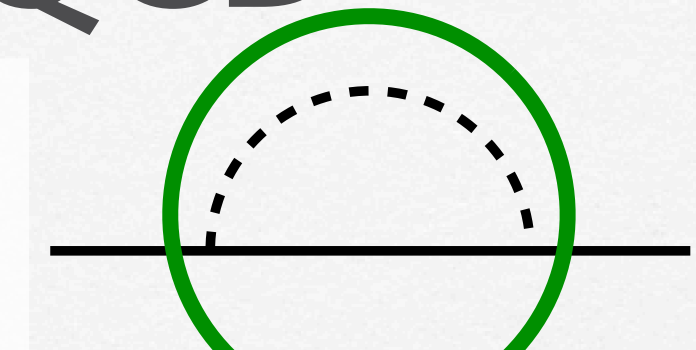
Gaussian

Independent-of-model chiral extrapolation

Quenched QCD vs QCD



RDY *et al.* PRD(2002)



Differences described by

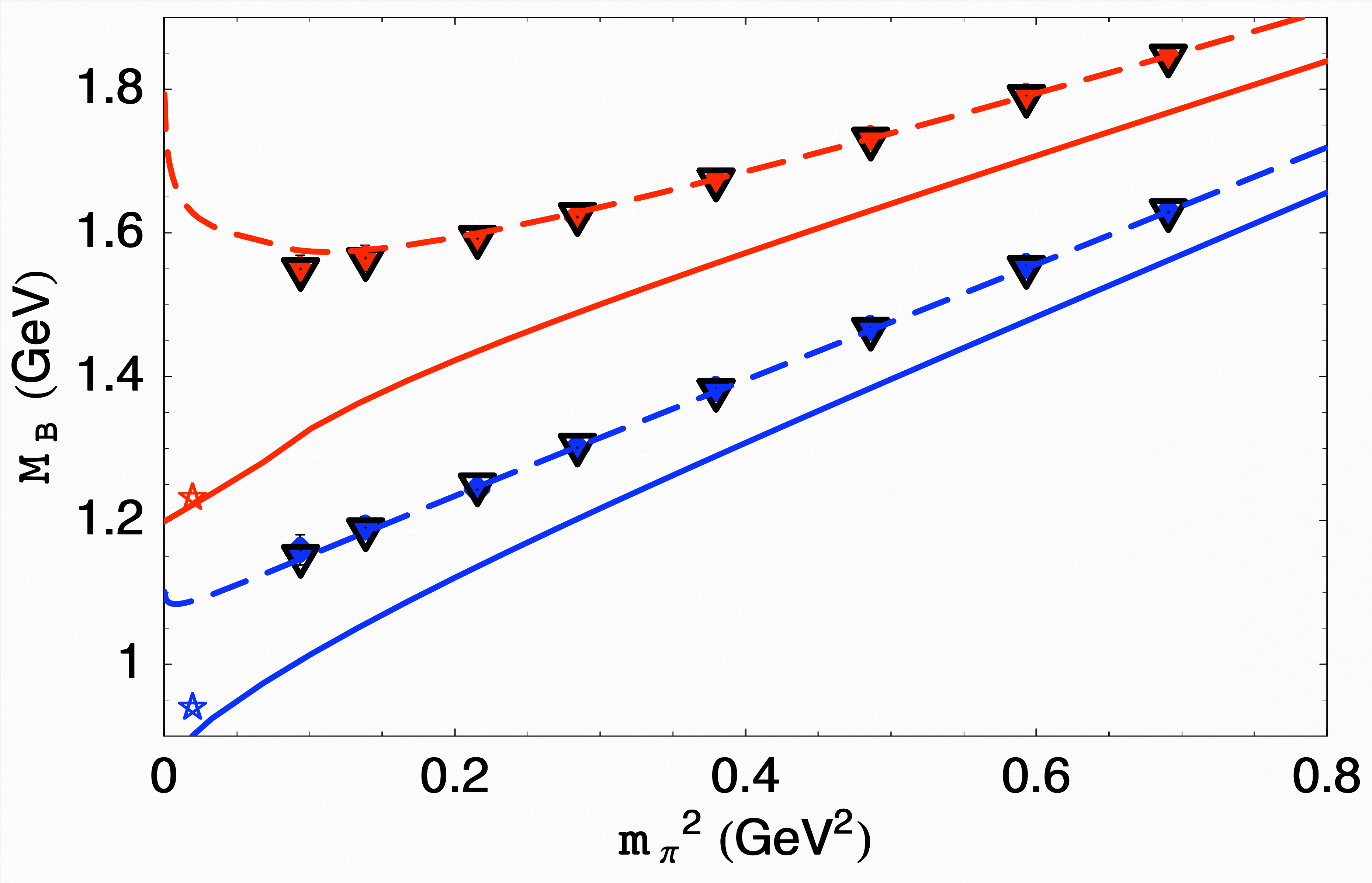
$$m_B = a_0 + a_2 m_\pi^2 + a_4 m_\pi^4 + \Sigma$$

	a0	a2	a4
N	1.23(1)	1.13(8)	-0.35(12)
N(Q)	1.20(1)	1.10(8)	-0.42(13)
D	1.40(3)	1.11(18)	-0.56(25)
D(Q)	1.43(3)	0.76(21)	-0.04(33)

What did that mean?

- Difference between quenched and dynamical lattice simulations are well-described by different meson-clouds
  - Empirical observation: not QCD proof
  - But proven successful
- Result: can take quenched lattice results to estimate QCD

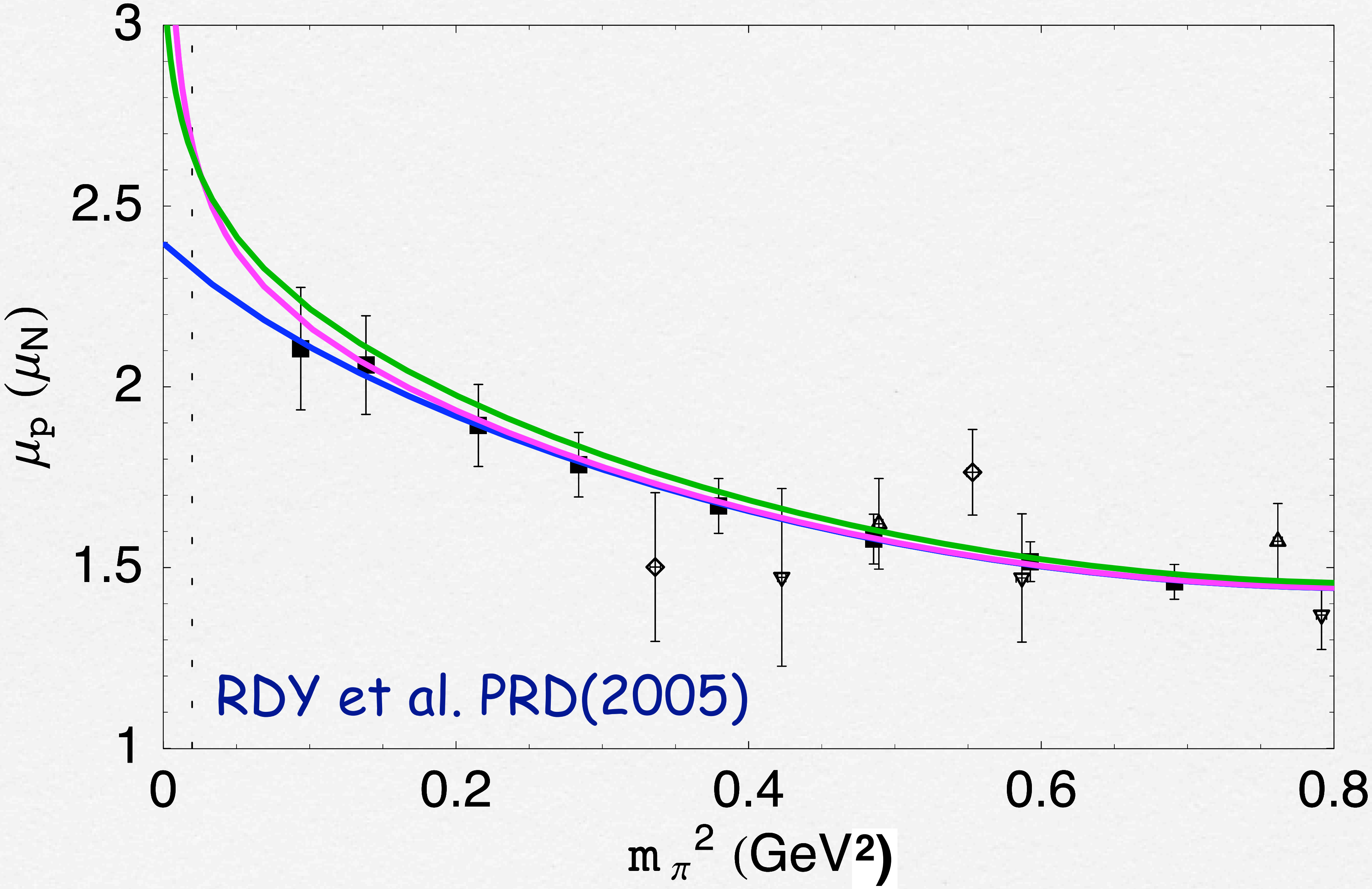
Baryon Masses



Lattice results:
Boinepalli et al. PLB(2005)

Using techniques just described:
RDY et al. PRD(2002)

Magnetic Moment



Finite-volume

Quenched

QCD

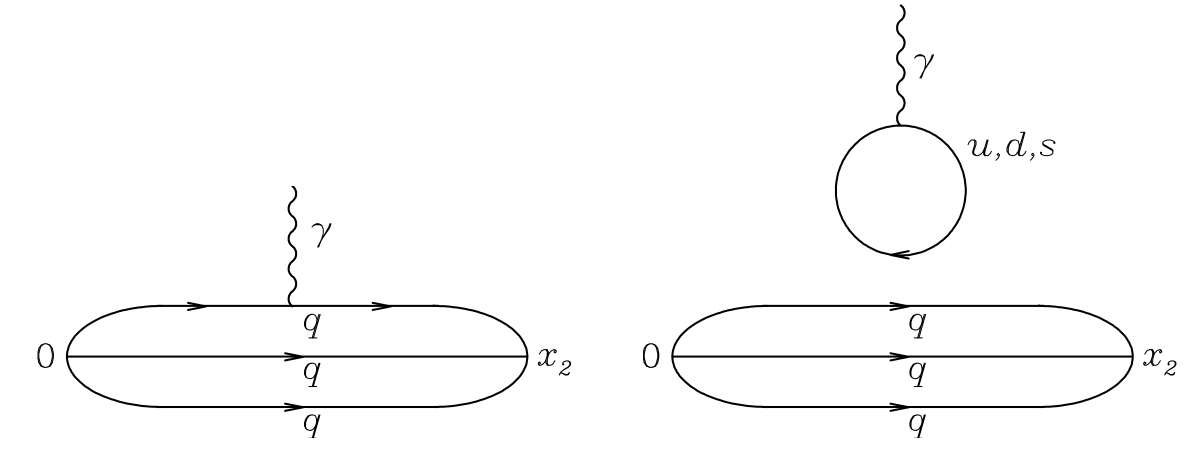
SUCCESS

Investigate applying technique to magnetic moment

Strangeness

- Apply techniques to strange form factors...

The Approach



Assume charge symmetry

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

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

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

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

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

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

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

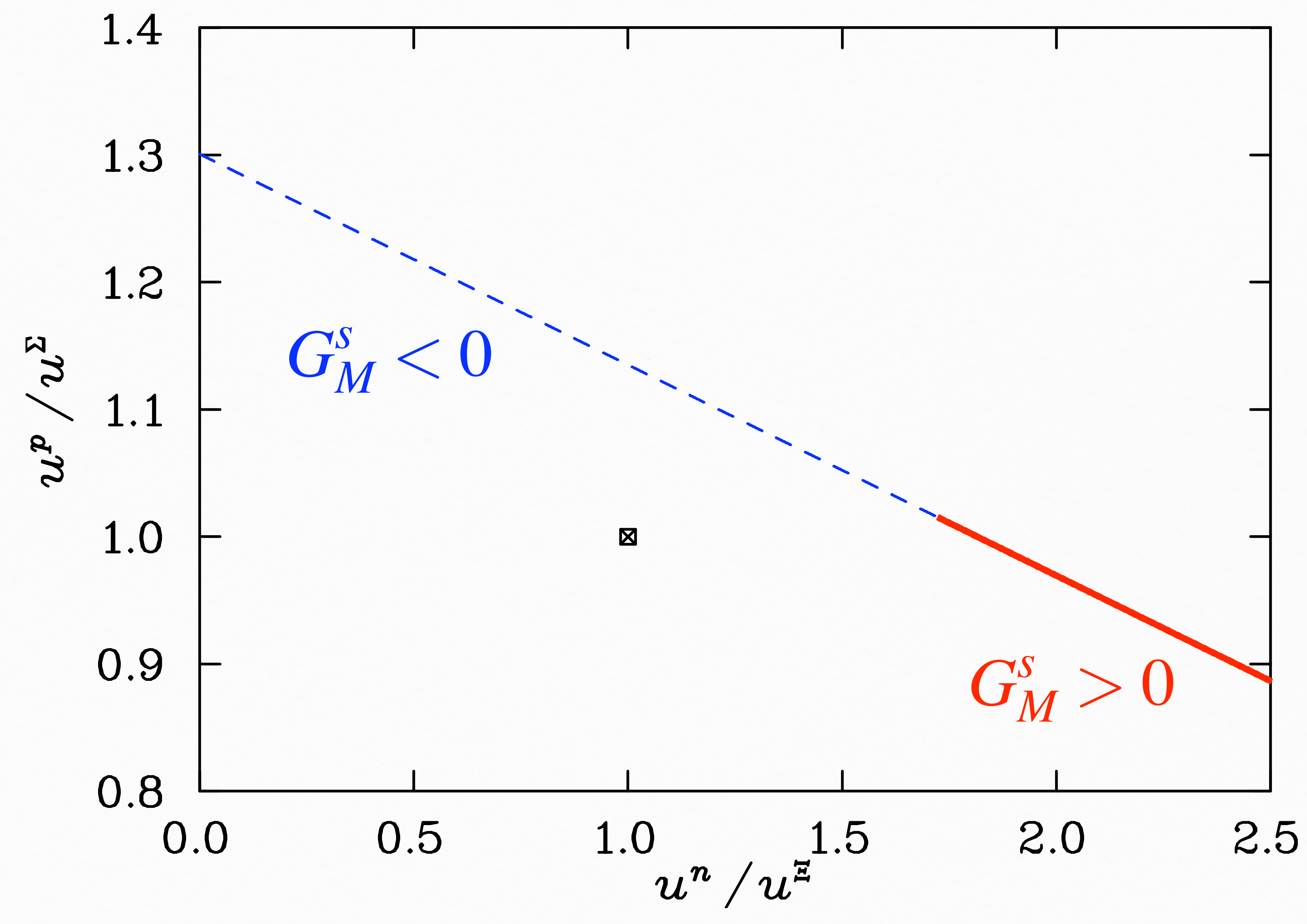
Lattice QCD

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

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

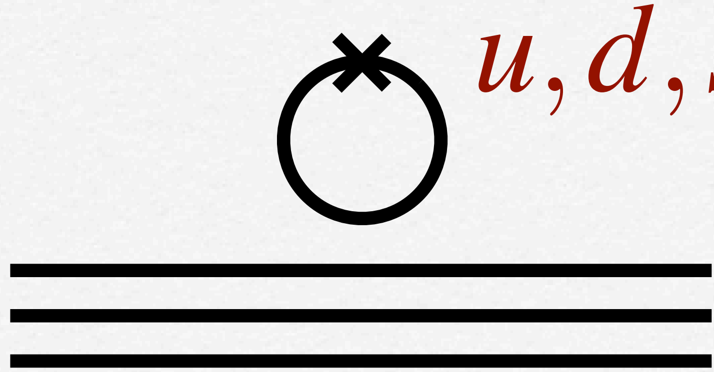
$$3O_N = p + 2n - \frac{u^n}{u^\Xi}(\Xi^0 - \Xi^-)$$

Constraint on GMs



Disconnected Loops

"l" loop contribution

$O_N =$  u, d, s $= \frac{2}{3}\,{}^{l}G_M^u - \frac{1}{3}\,{}^{l}G_M^d - \frac{1}{3}\,{}^{l}G_M^s$

$${}^{l}G_M^u = {}^{l}G_M^d$$

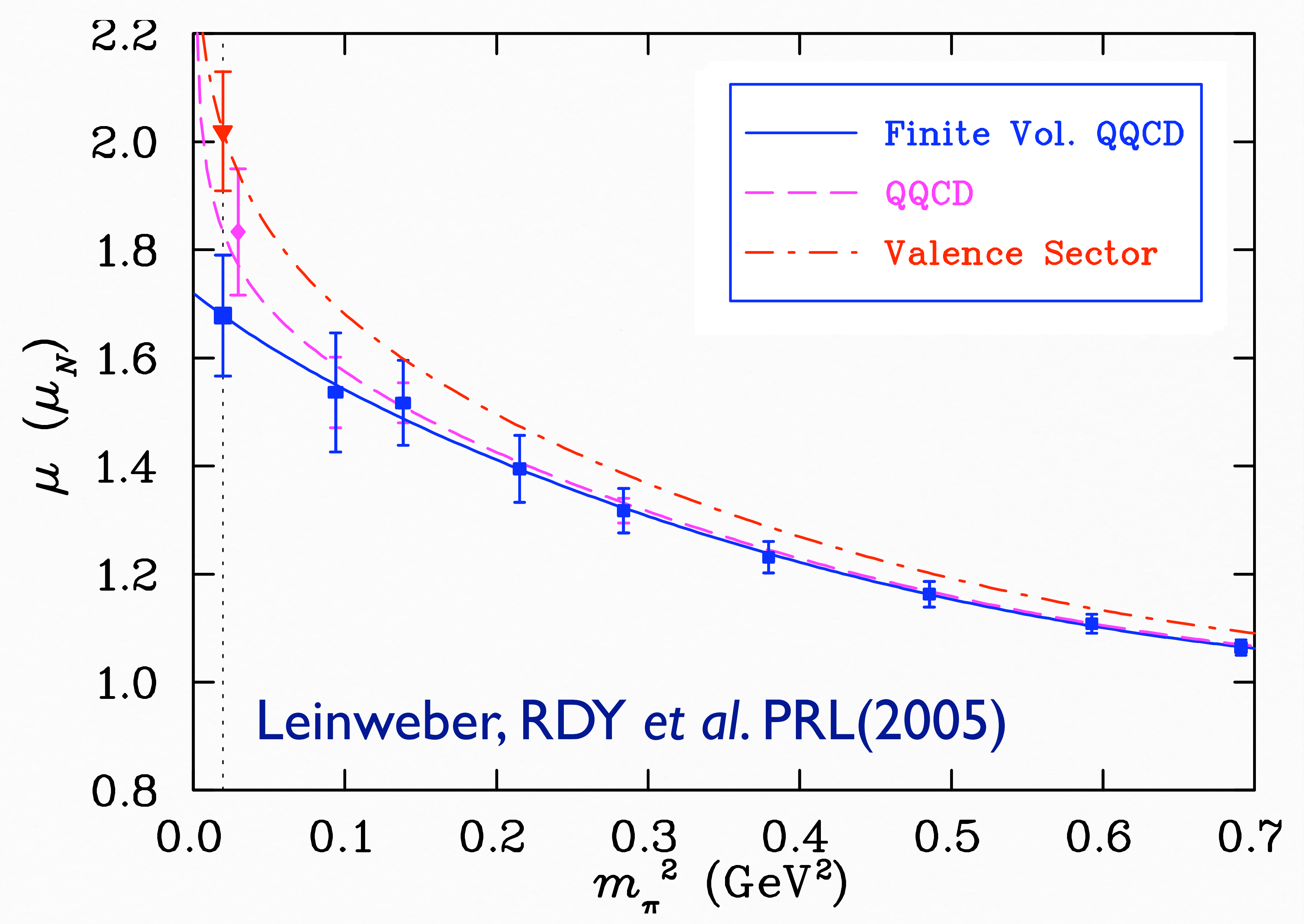
QCD equality for $m_u = m_d$

$$O_N = -\frac{1}{3}\left({}^{l}G_M^d + {}^{l}G_M^s\right) = \frac{{}^{l}G_M^s}{3}\left(\frac{1 - {}^{l}R_d^s}{{}^{l}R_d^s}\right)$$

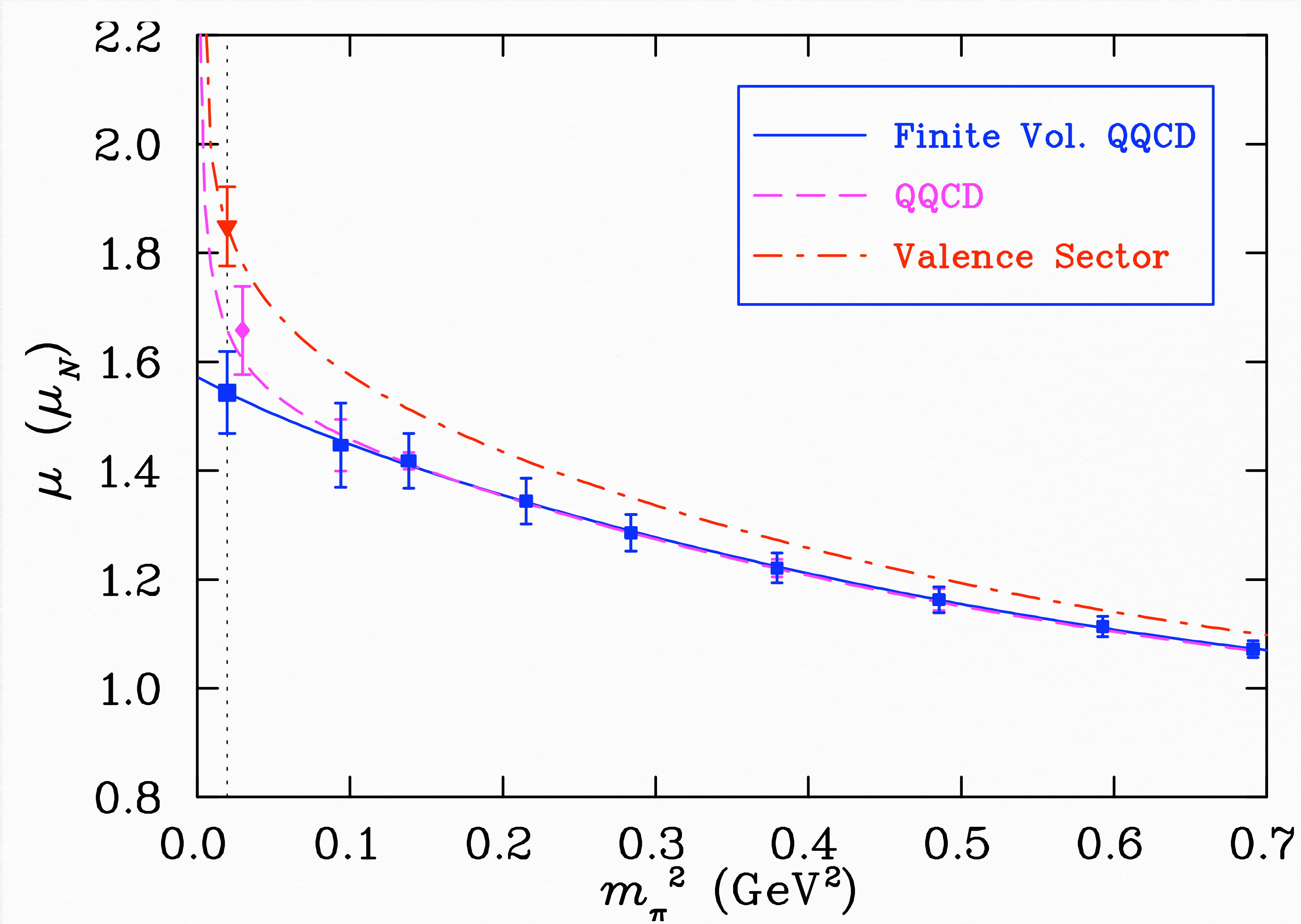
$${}^{l}R_d^s = {}^{l}G_M^s / {}^{l}G_M^d = 0.139 \pm 0.042$$

Kaon strength relative to pion

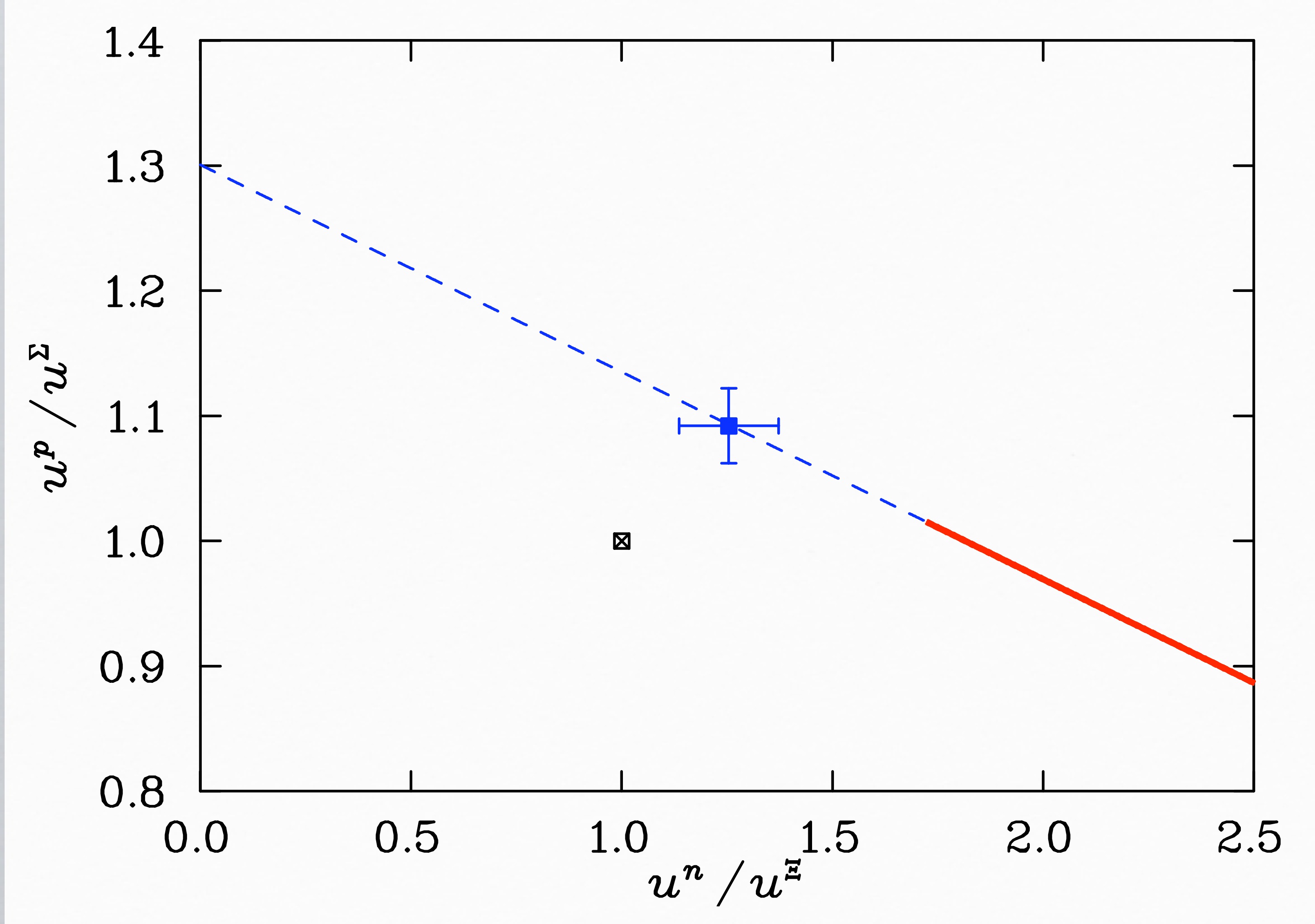
u-quark in proton



u-quark in Sigma



Final Result

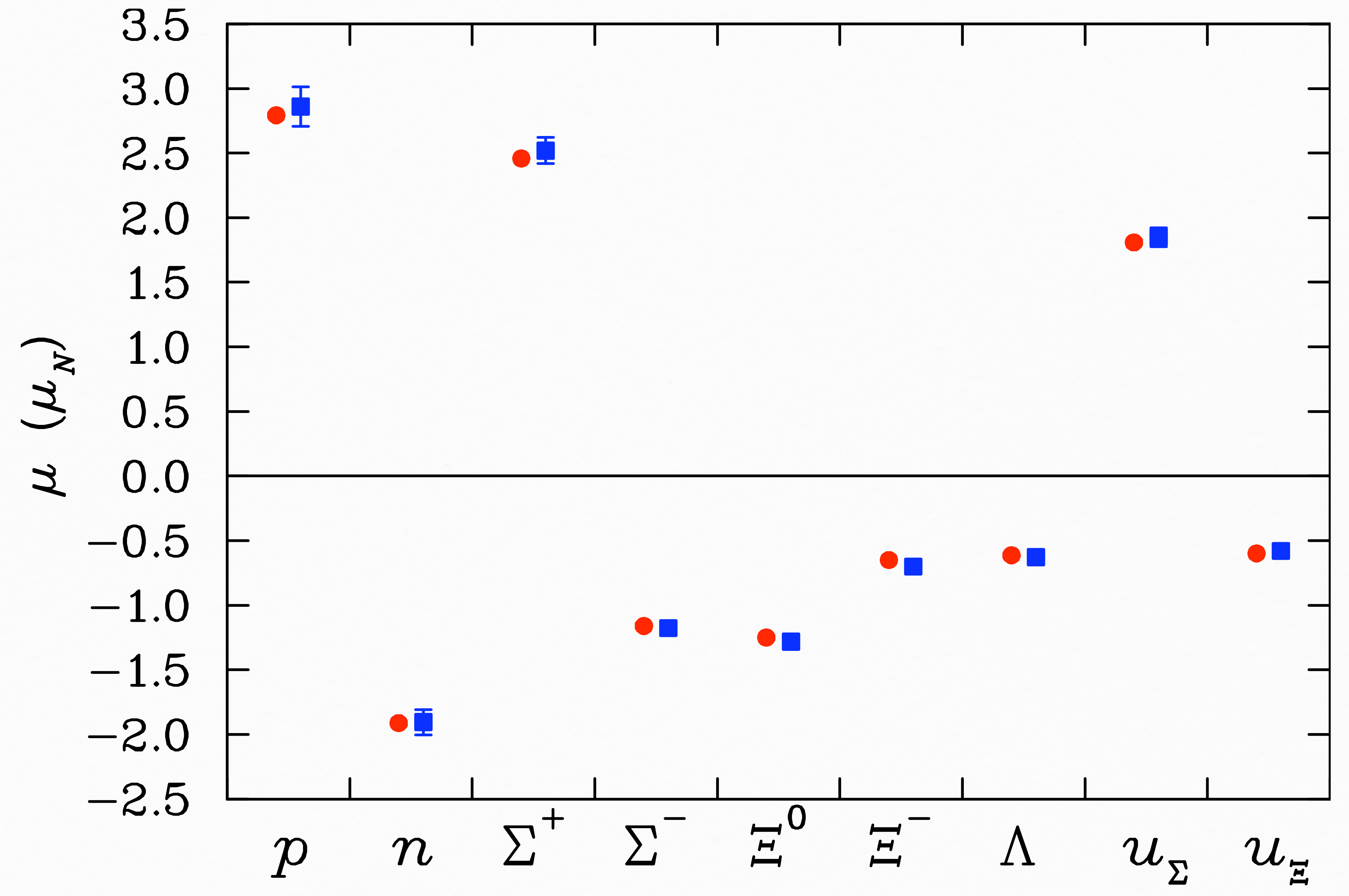


$$\frac{u^p}{u^\Sigma} = 1.092 \pm 0.030$$

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

$$G_M^s = -0.046 \pm 0.022\, \mu_N$$

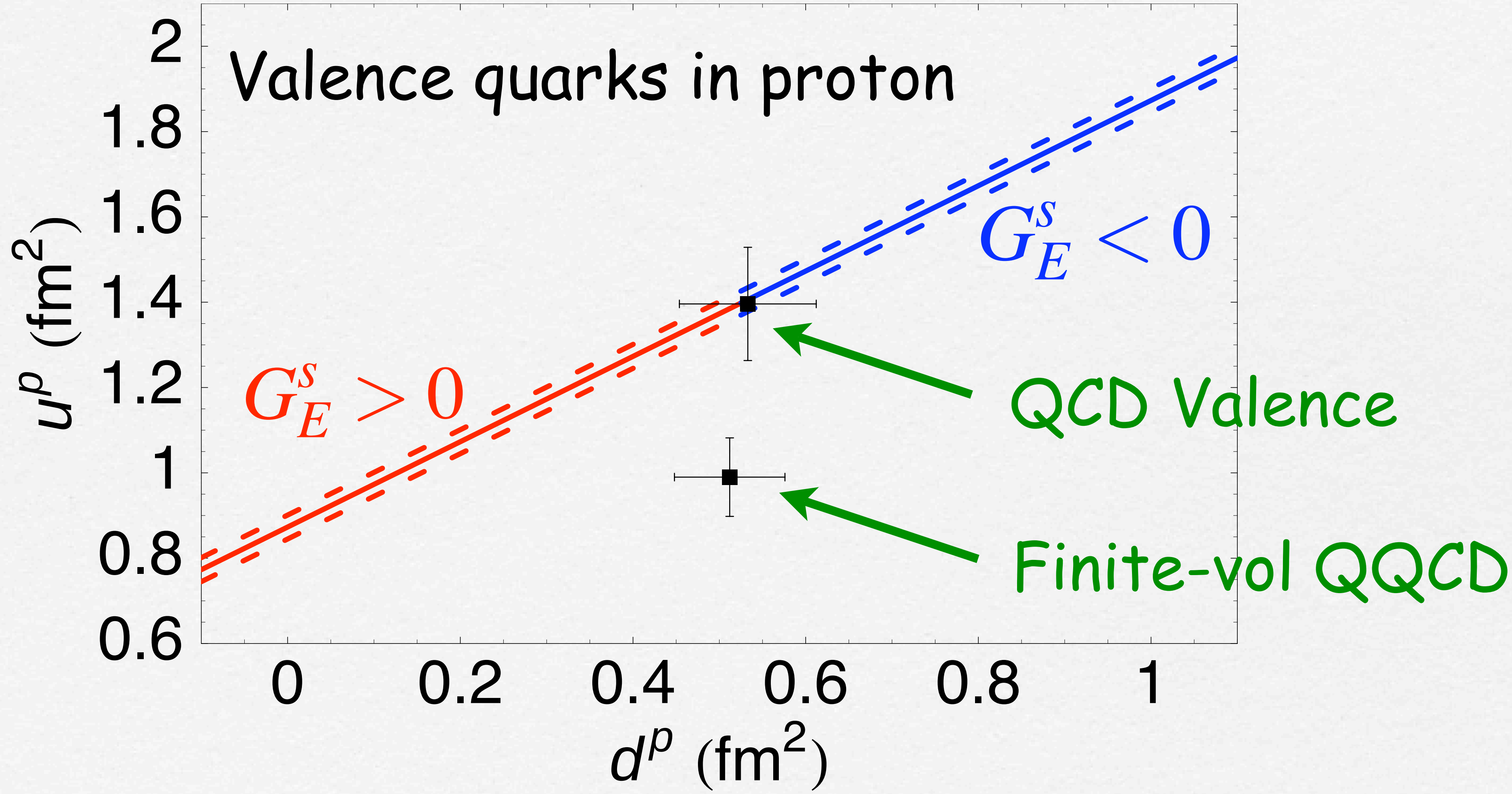
Magnetic Moments



Leinweber et al. PRL(2005)

Repeat for electric radius

Limited hyperon info, take absolute values from lattice

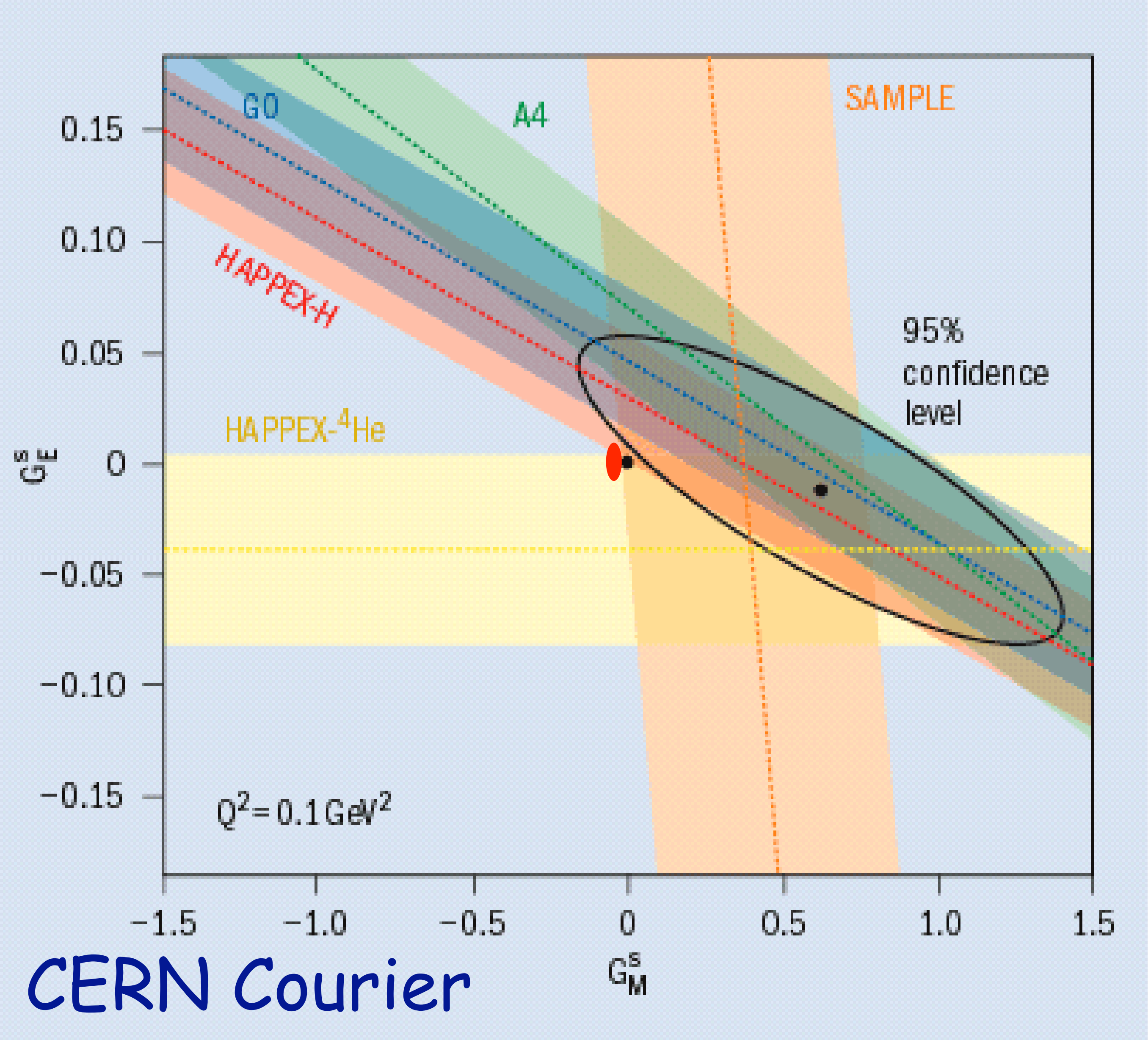


$$G_E^s(Q^2 = 0.1) = +0.001 \pm 0.004 \pm 0.004$$

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

Experimental Status

- World PVES data

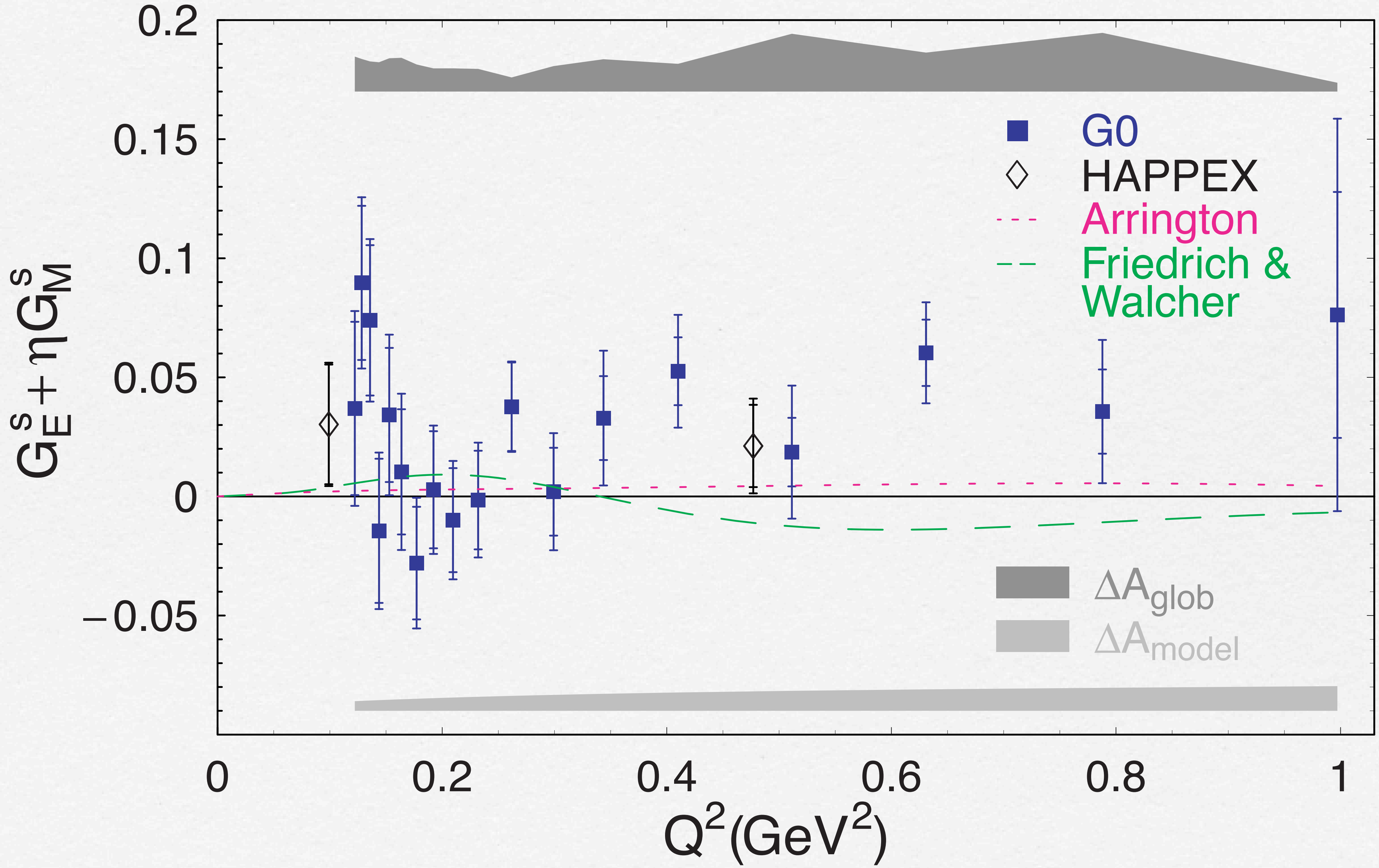


$$Q^2 = 0.1\,\mathrm{GeV}^2$$

Analysis relies upon theoretical bounds on anapole contribution, Zhu et al. PRD(2000)

G0 Experiment

PRL95(2005)



Global Analysis

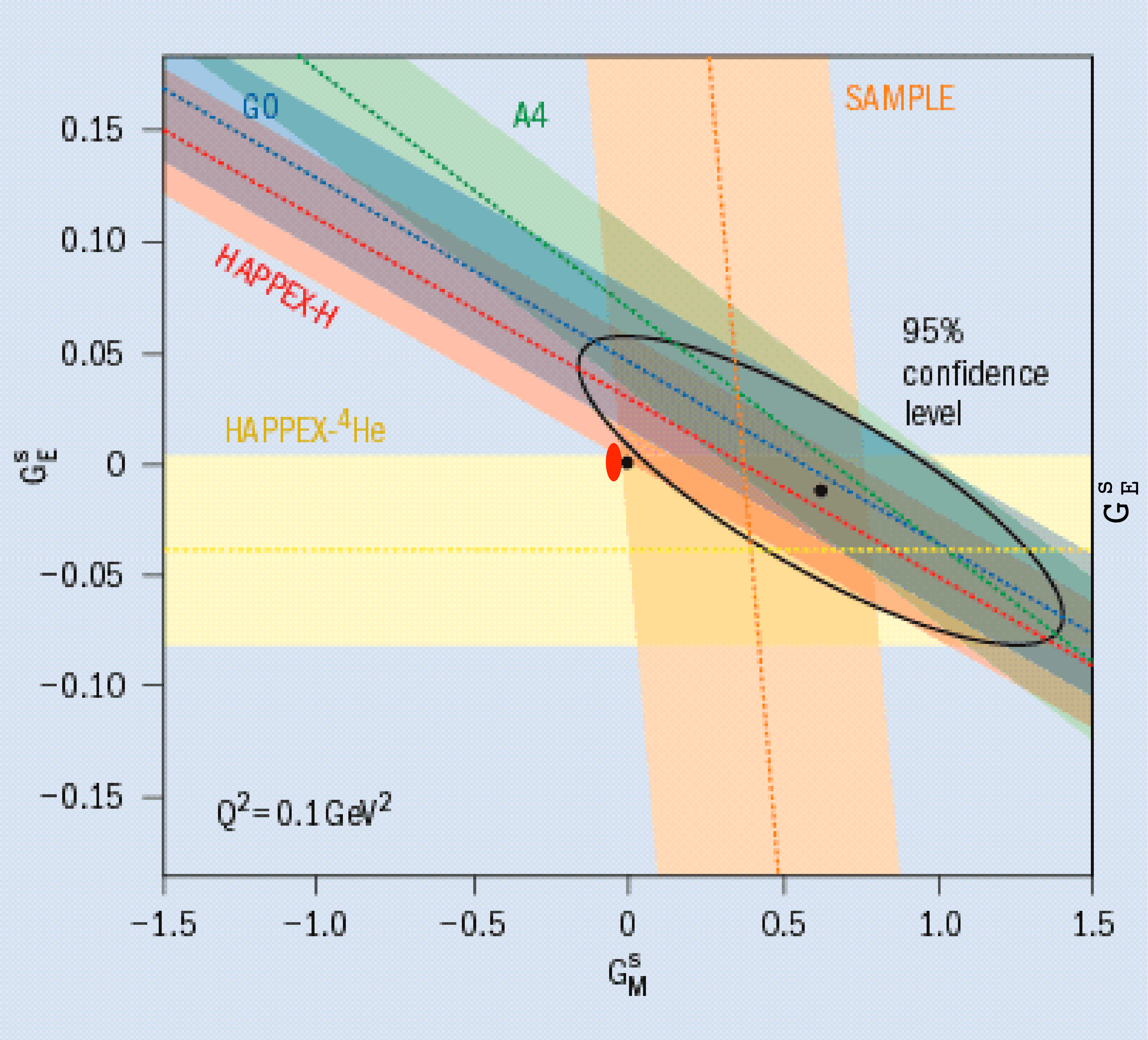
RDY *et al.* nucl-ex/0604010

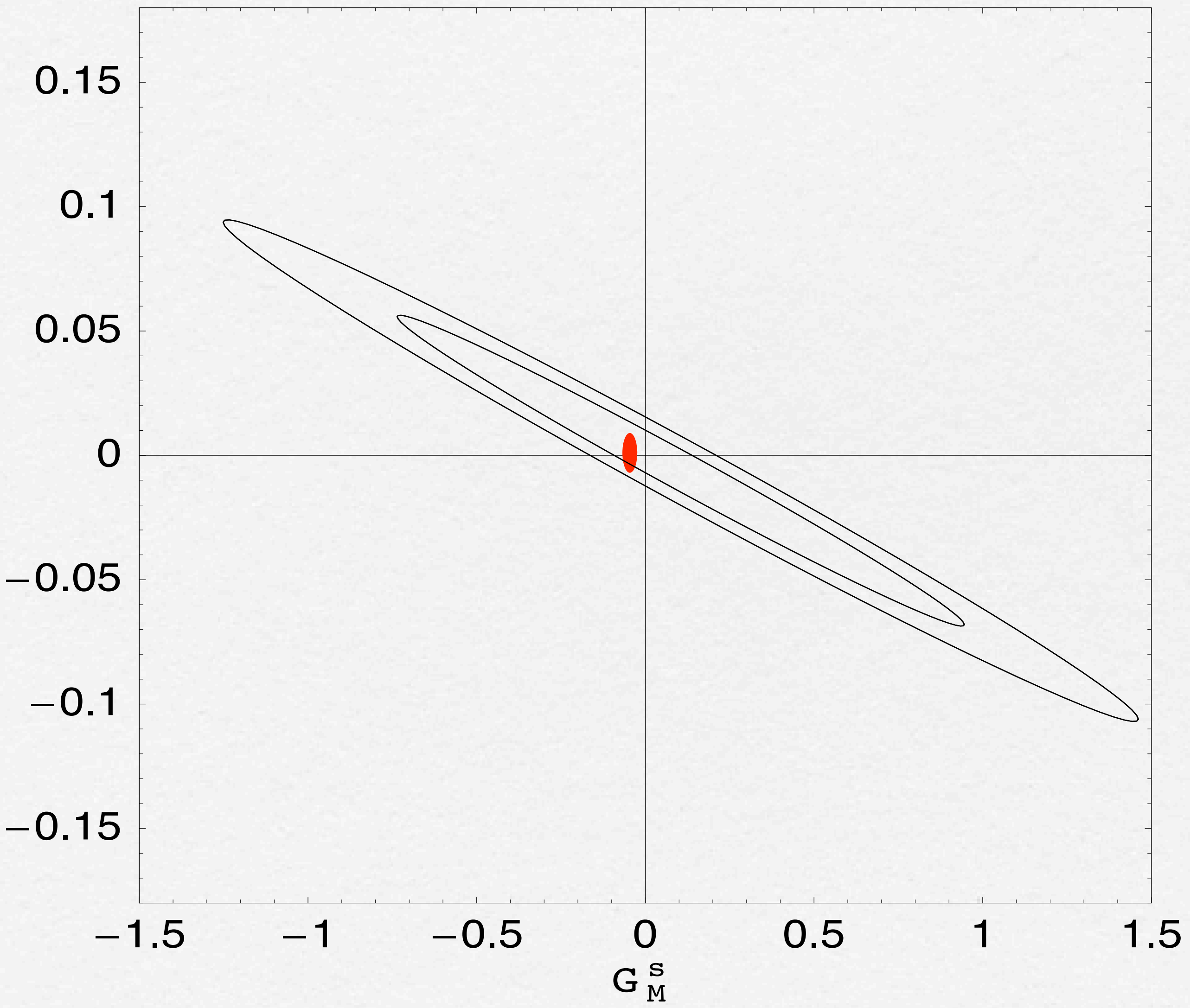
- All data for $Q^2 < 0.3\,\mathrm{GeV}^2$
- Extract axial ff (anapole moment)

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

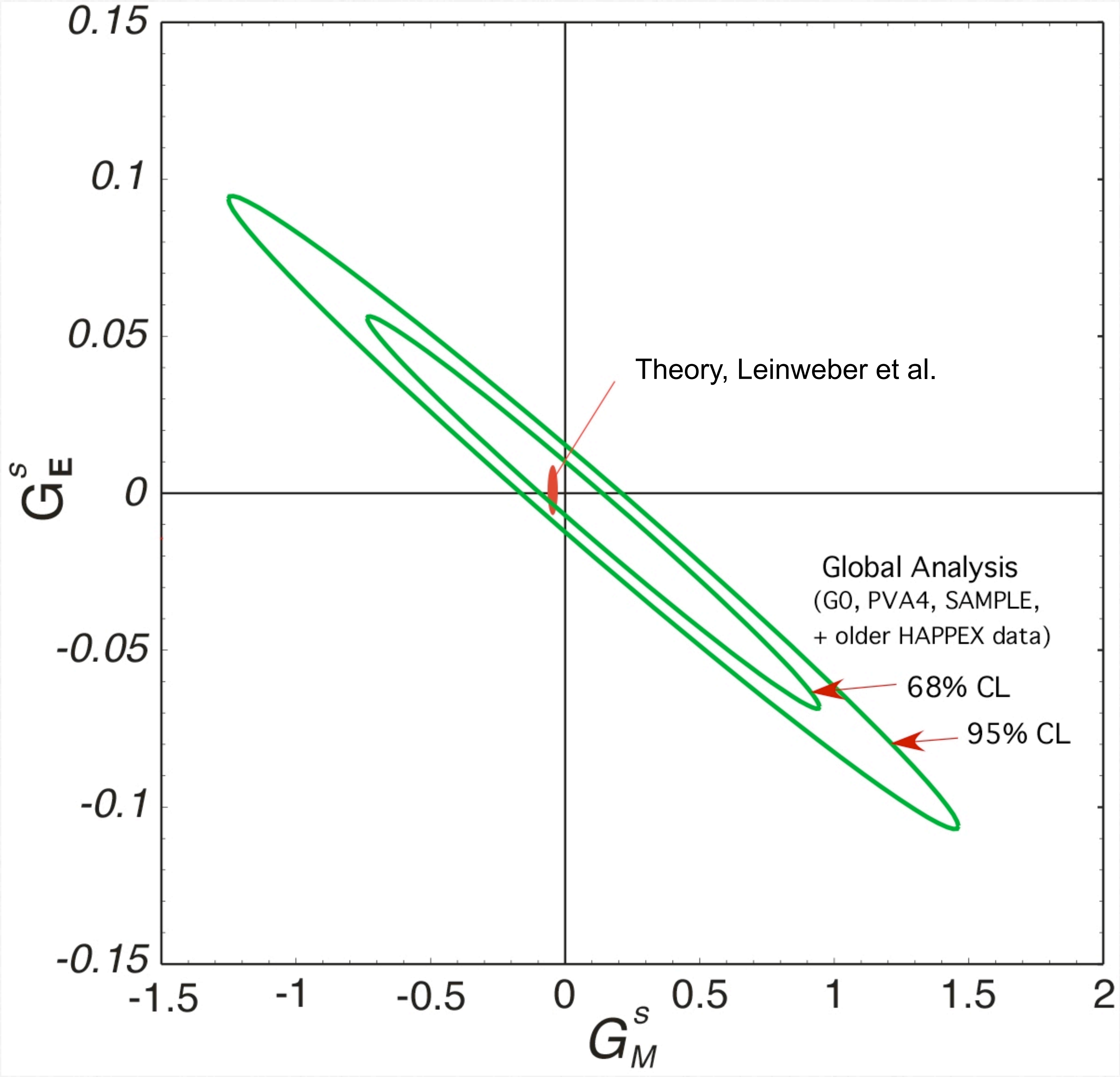
$$G_E^s = \rho_s Q^2 + \rho_s' Q^4 + \dots$$
$$G_M^s = \mu_s + \mu_s' Q^2 + \dots$$

GMs–GEs





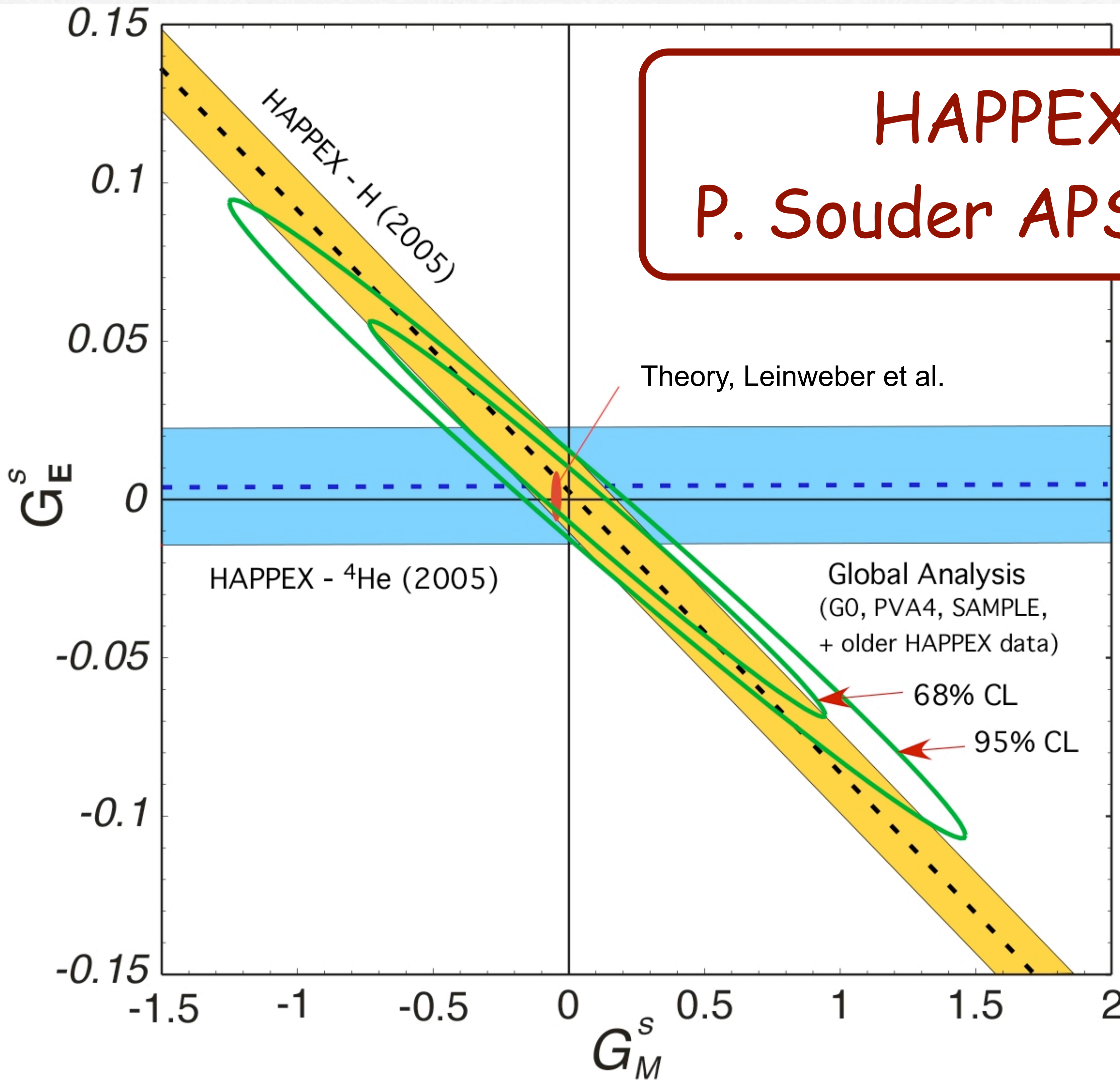
RDY *et al.* nucl-ex/0604010

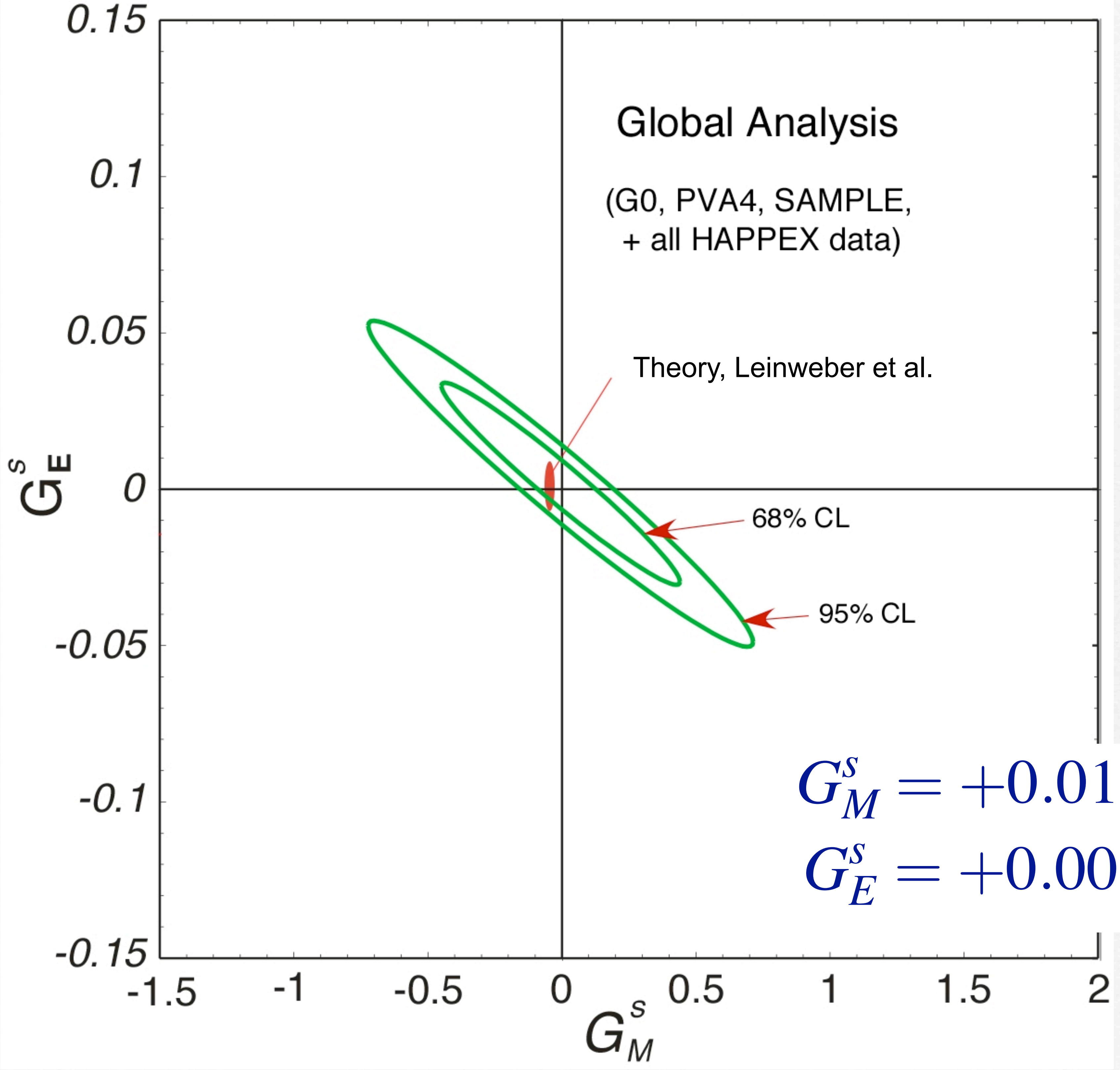


0.15
0.1
0.05
0
-0.05
-0.1
-0.15
-1.5
-1
-0.5
0
0.5
1
1.5
2
G_E^s
G_M^s
Theory, Leinweber et al.
Global Analysis
(G0, PVA4, SAMPLE,
+ older HAPPEX data)
68% CL
95% CL

HAPPEX

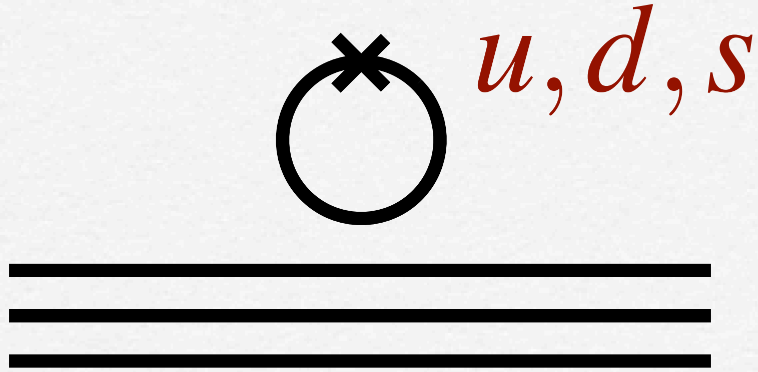
P. Souder APS2006





$$G_M^s = +0.01 \pm 0.29\,\mu_N$$
$$G_E^s = +0.002 \pm 0.021$$

Disconnected Loops



$$= \frac{2}{3}{}^{l}G_M^u - \frac{1}{3}{}^{l}G_M^d - \frac{1}{3}{}^{l}G_M^s$$

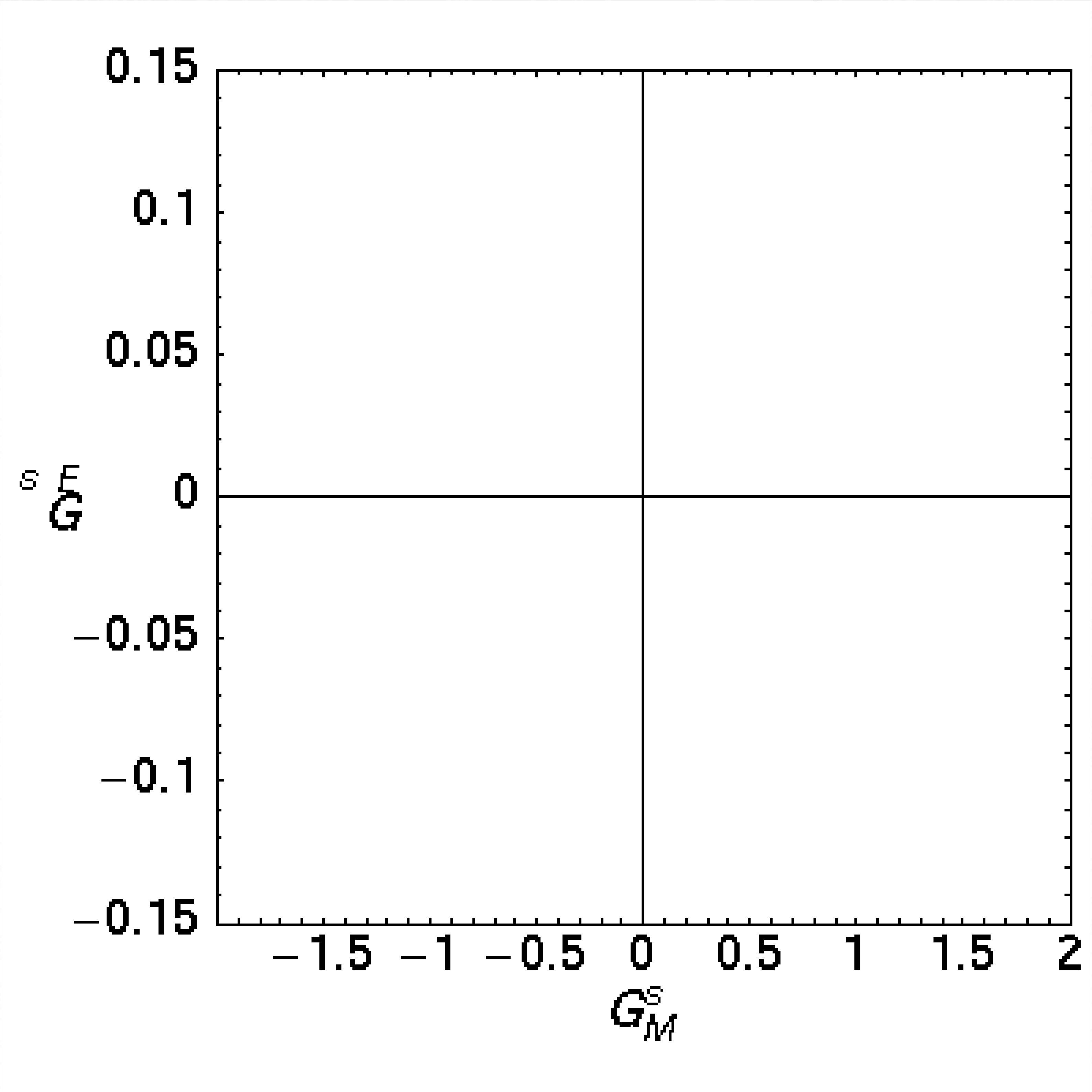
-6%   +3%   +0.5%

Remarks

- Excellent phenomenological description of sea quark effects in lattice simulations
- Predictions for strange FFs supported by experiment
- New precision in PVES is remarkable

$$\langle r^2\rangle_E^p = 0.766 \pm 0.012\,\mathrm{fm}^2$$
$$\langle r^2\rangle_E^s = 0.001 \pm 0.017\,\mathrm{fm}^2$$

- Advancing knowledge on how QCD works!



Thanks:

Derek Leinweber
Tony Thomas

Roger Carlini
Julie Roche

Sharada Boinepalli
Ian Cloet
Ping Wang
Tony Williams
James Zanotti
Jianbo Zhang

HAPPEx