Precise Determination of the Strange Form Factors of the Nucleon

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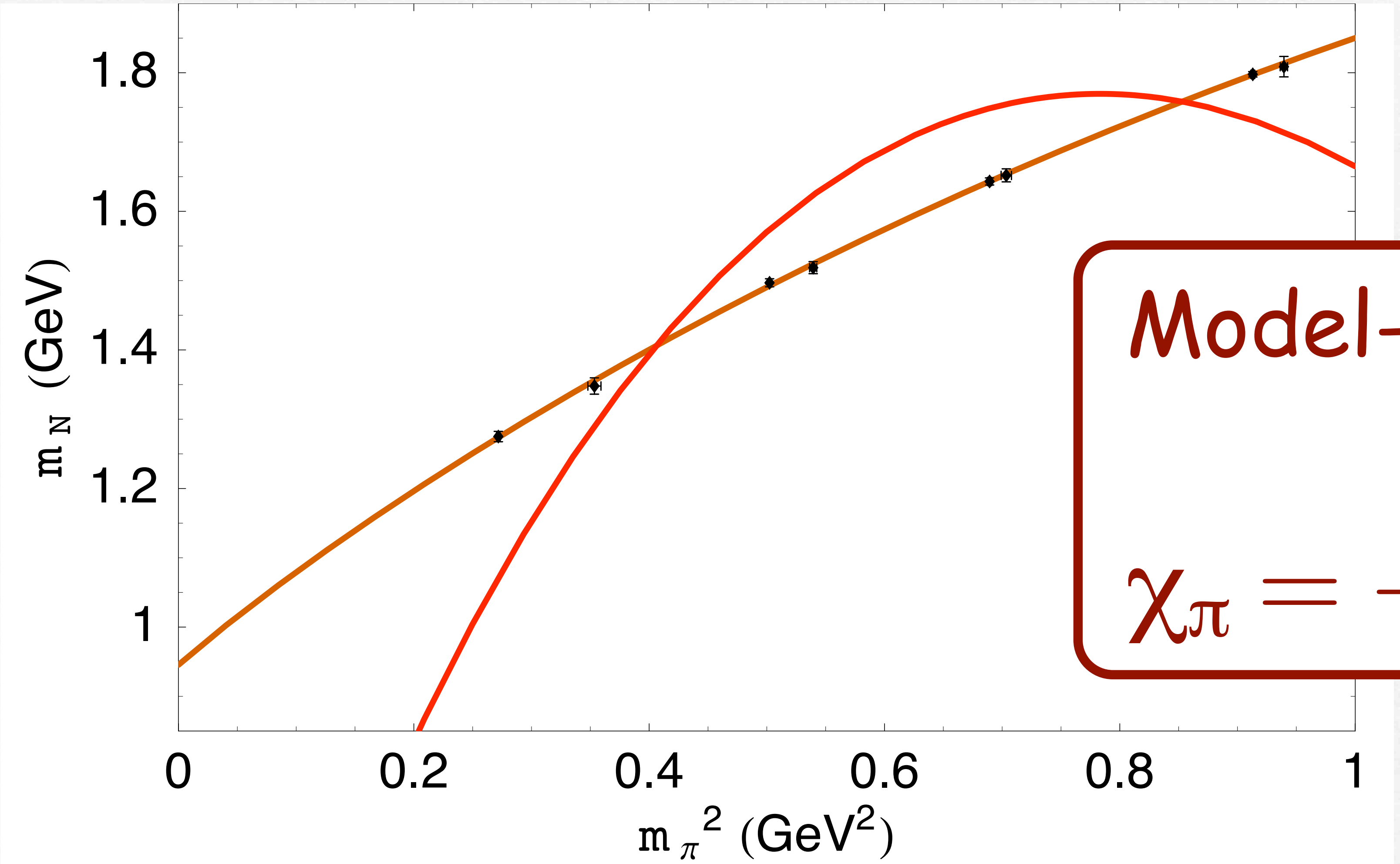
Outline

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

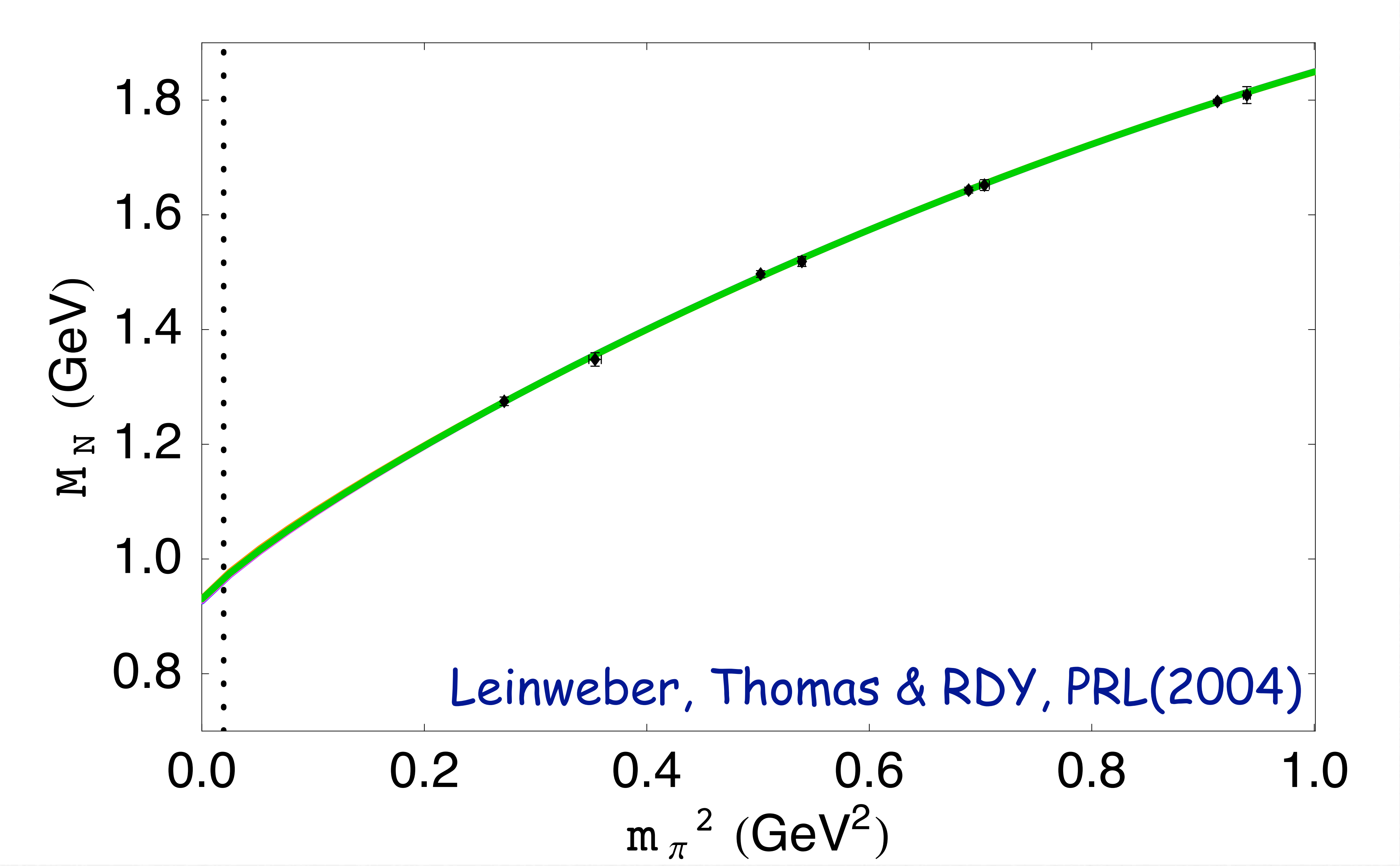


Model-independent value

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

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

Finite-range regularisation



Dipole

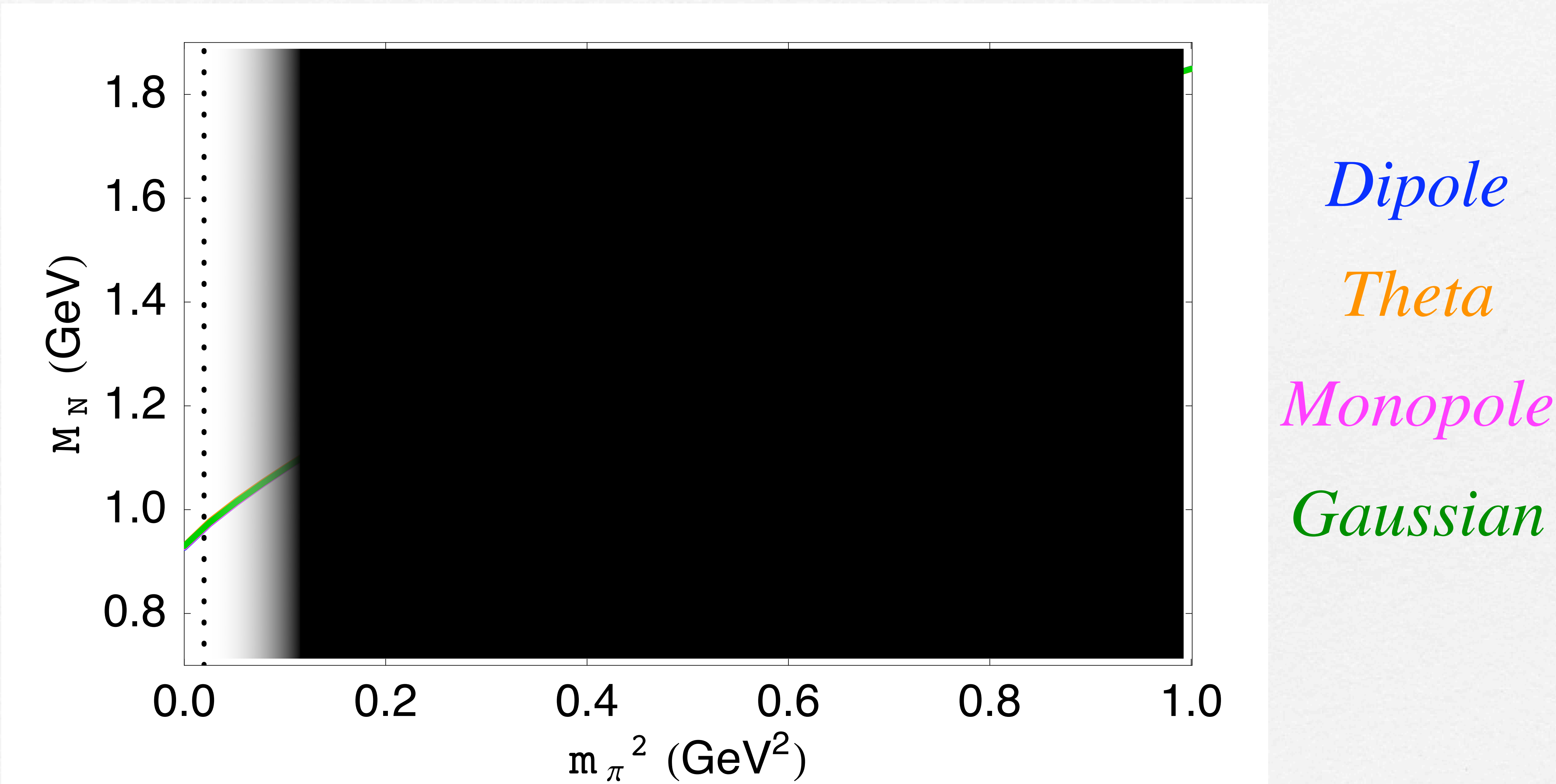
Theta

Monopole

Gaussian

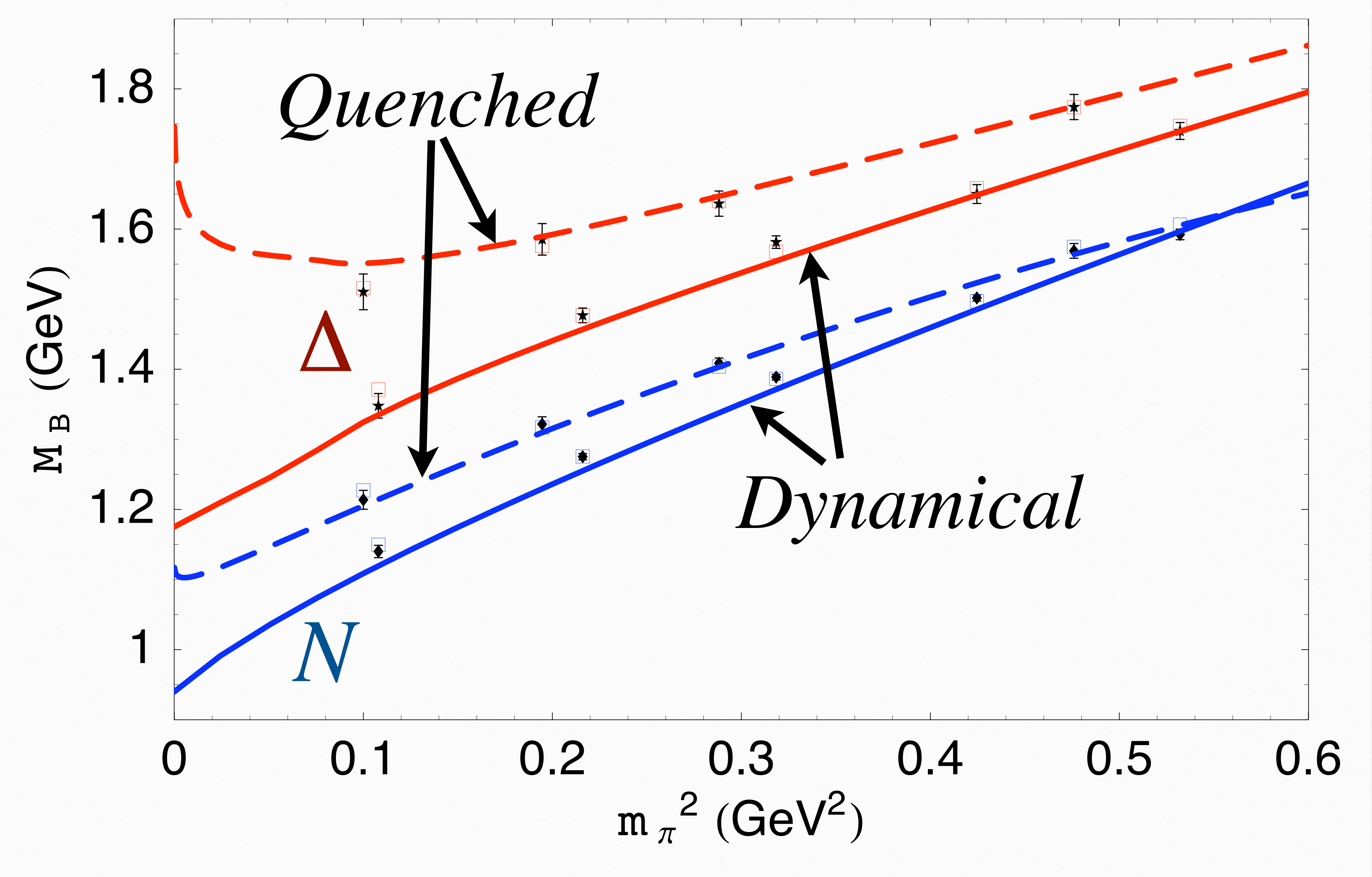
Independent-of-model chiral extrapolation

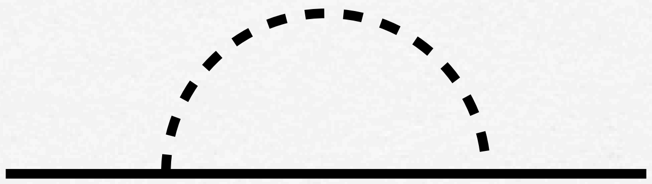
Finite-range regularisation



Independent-of-model chiral extrapolation

Quenched QCD vs QCD

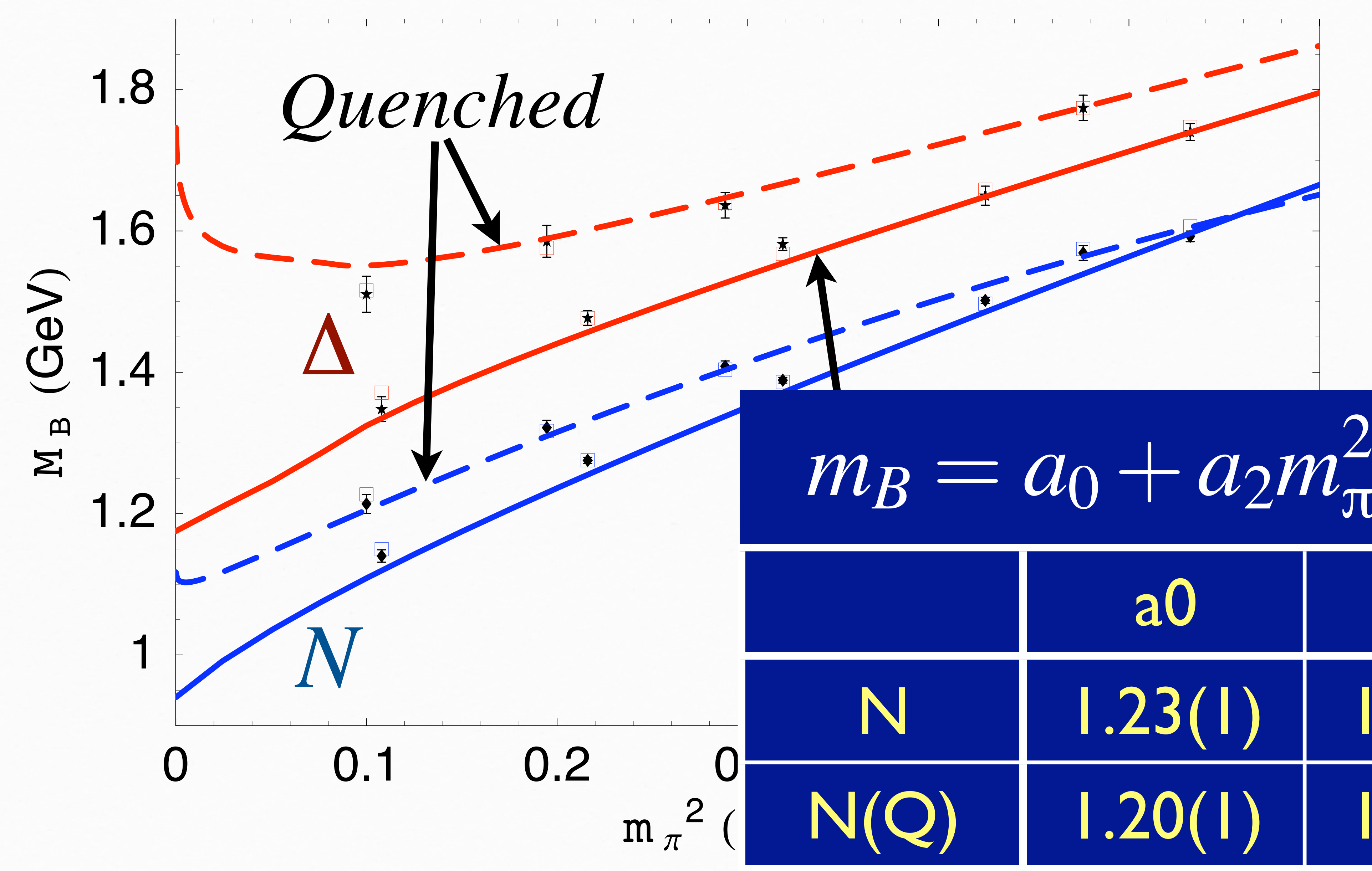


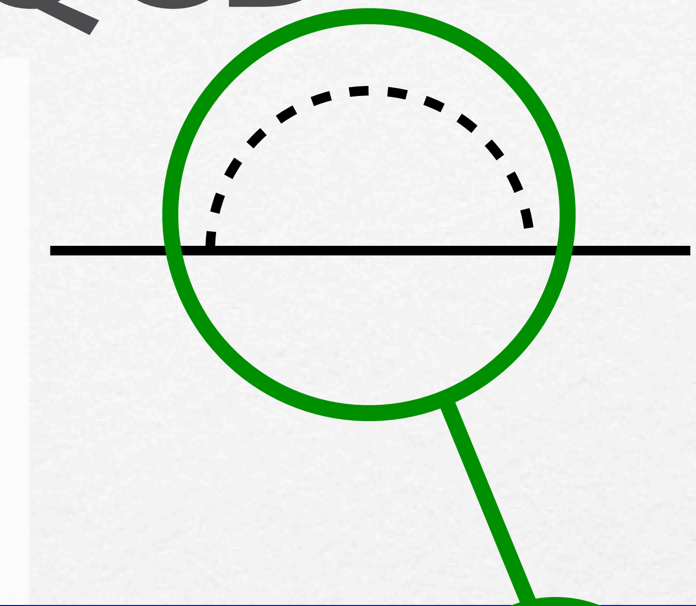


Differences described by chiral loops

RDY *et al.* PRD(2002)

Quenched QCD vs QCD





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

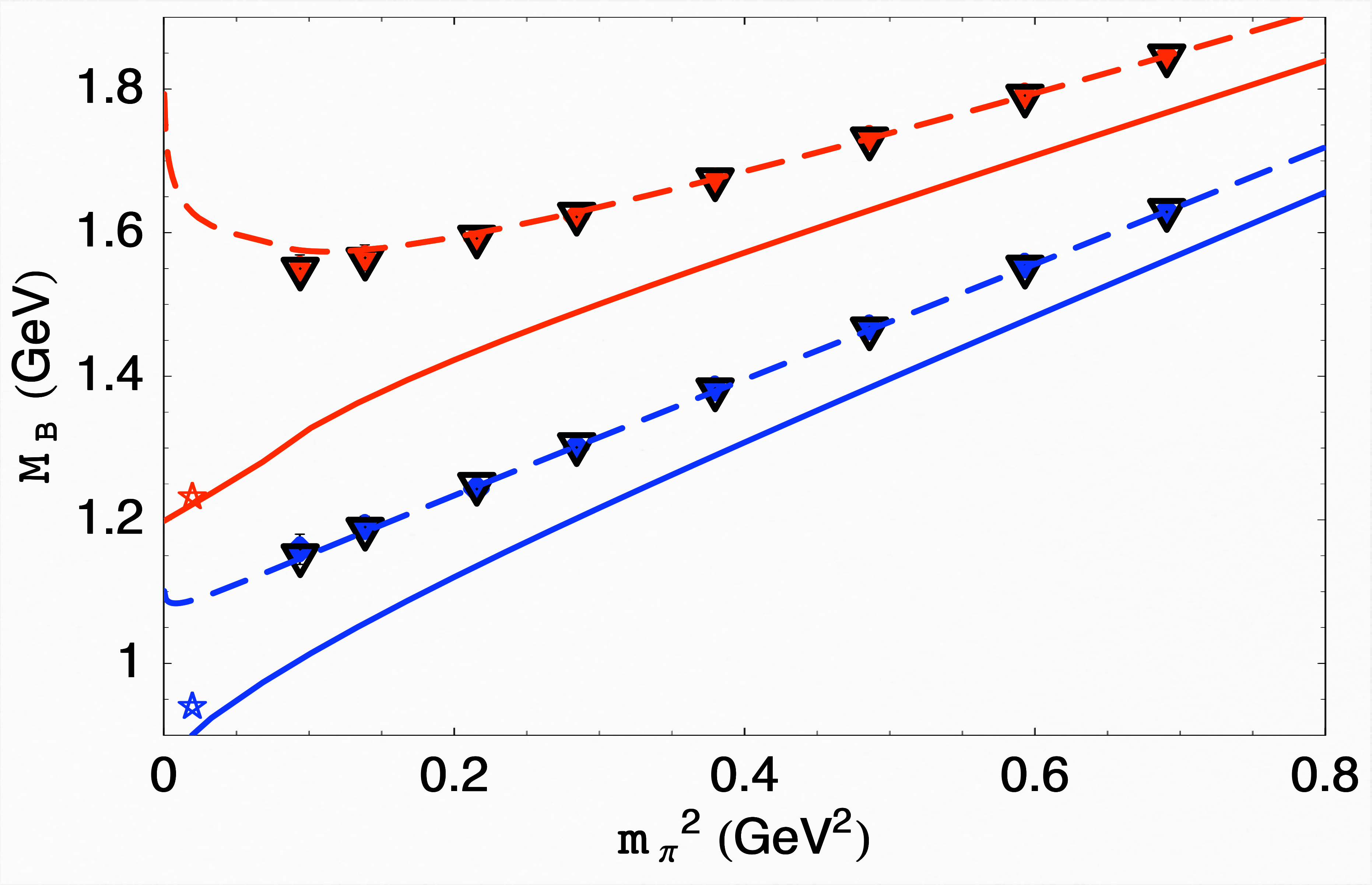
	a0	a2	a4
N	1.23(1)	1.13(8)	-0.35(12)
N(Q)	1.20(1)	1.10(8)	-0.42(13)
D	1.40(3)	1.11(18)	-0.56(25)
D(Q)	1.43(3)	0.76(21)	-0.04(33)

RDY *et al.* PRD(2002)

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



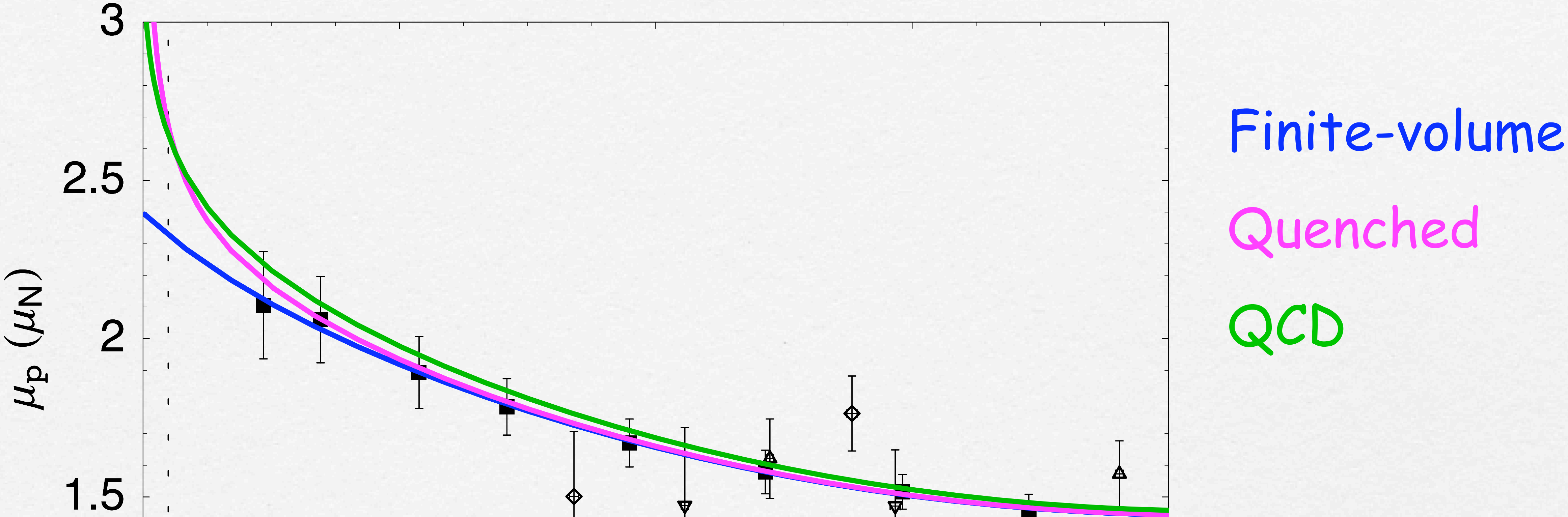
Lattice results:

Boinepalli et al. PLB(2005)

Using techniques just described:

RDY et al. PRD(2002)

Magnetic Moment

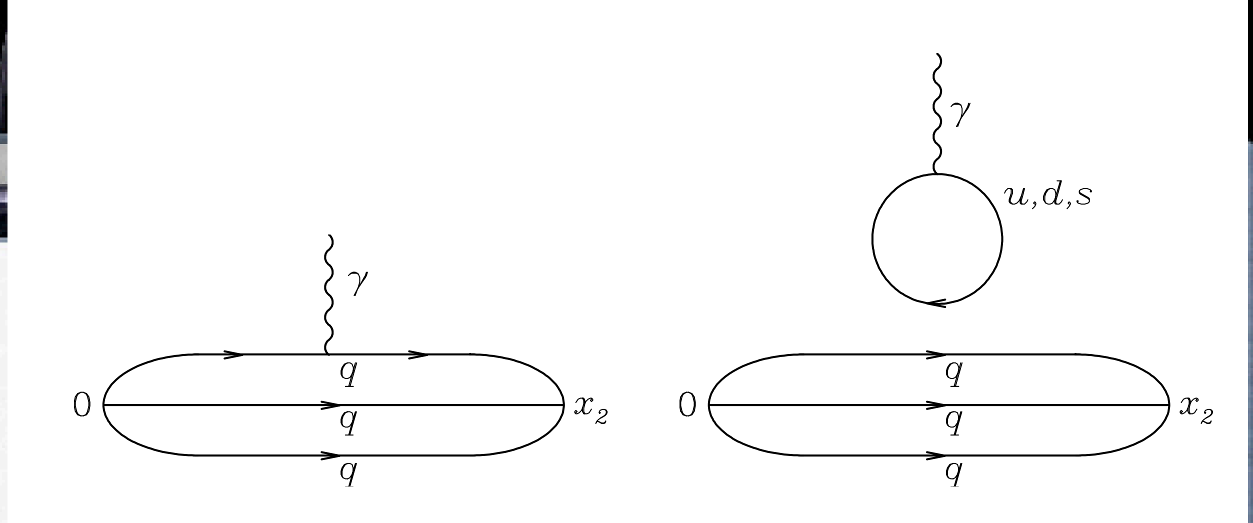


Investigate applying technique to magnetic moment

Strangeness

- Apply techniques to strange form factors...

The Approach



Assume charge symmetry

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

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

$$3O_N = 2p + n - u^p \qquad \Sigma^+ - \Sigma^- = u^\Sigma$$

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

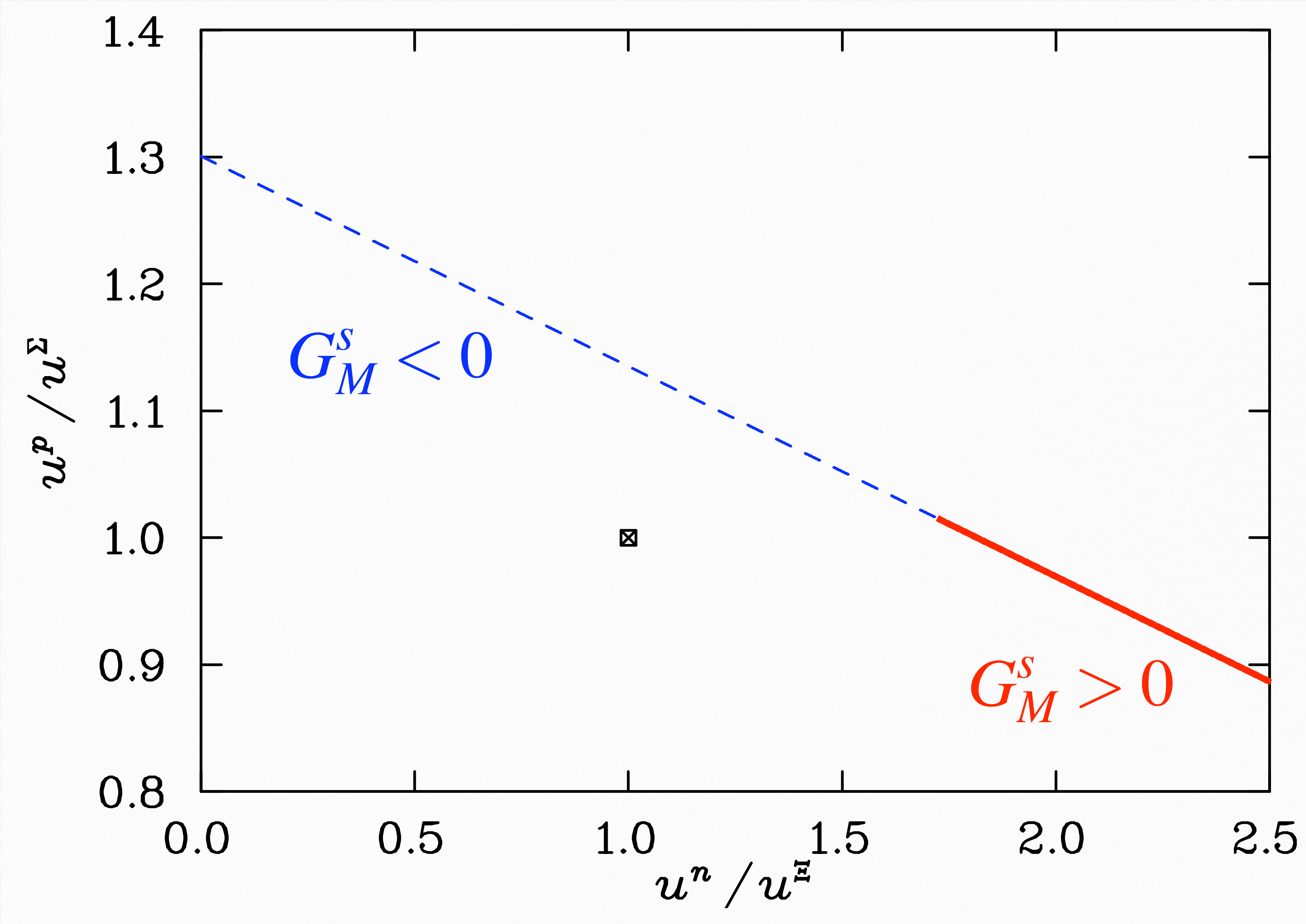
Lattice QCD

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

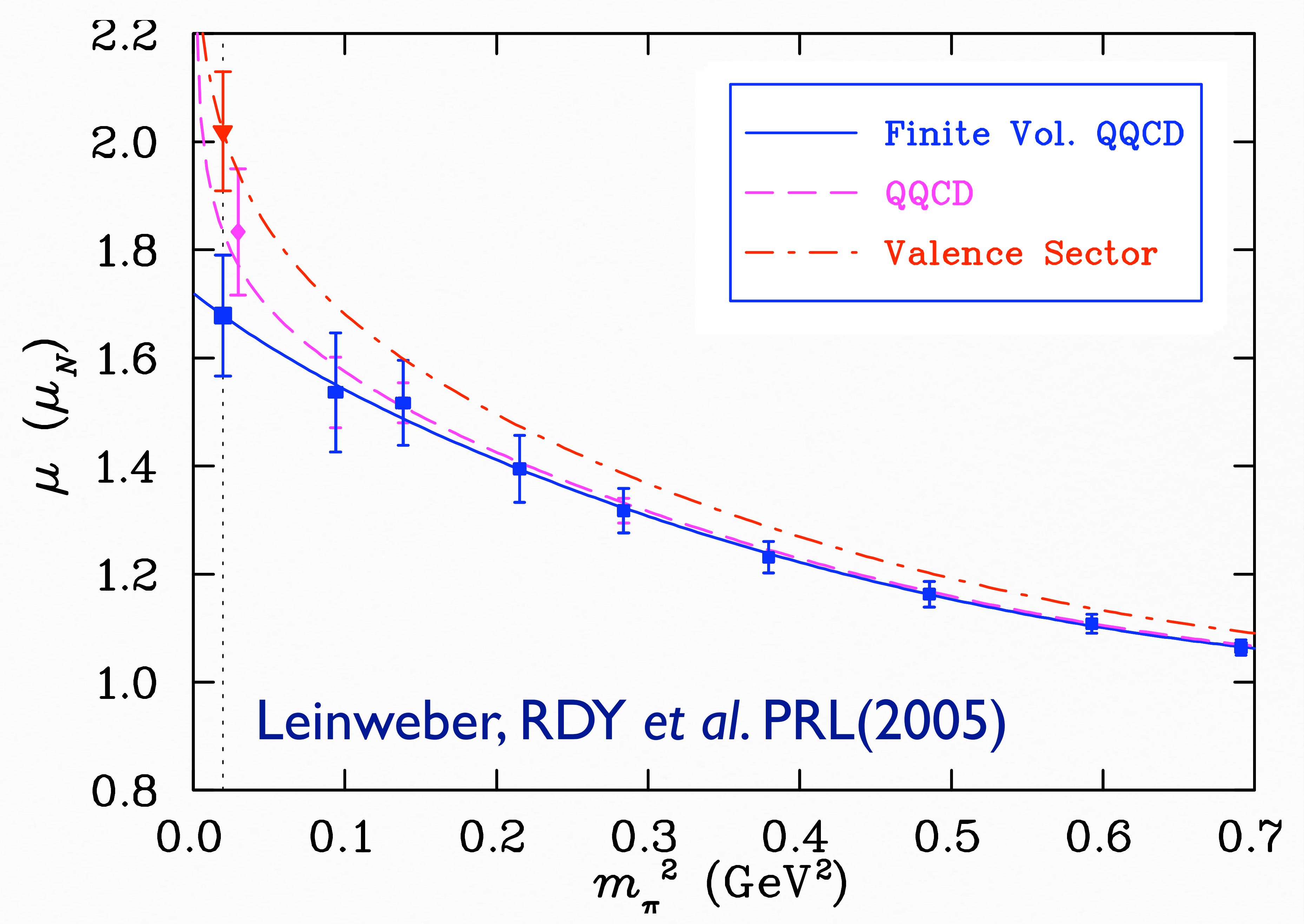
$$\Xi^0 - \Xi^- = u^\Xi$$

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

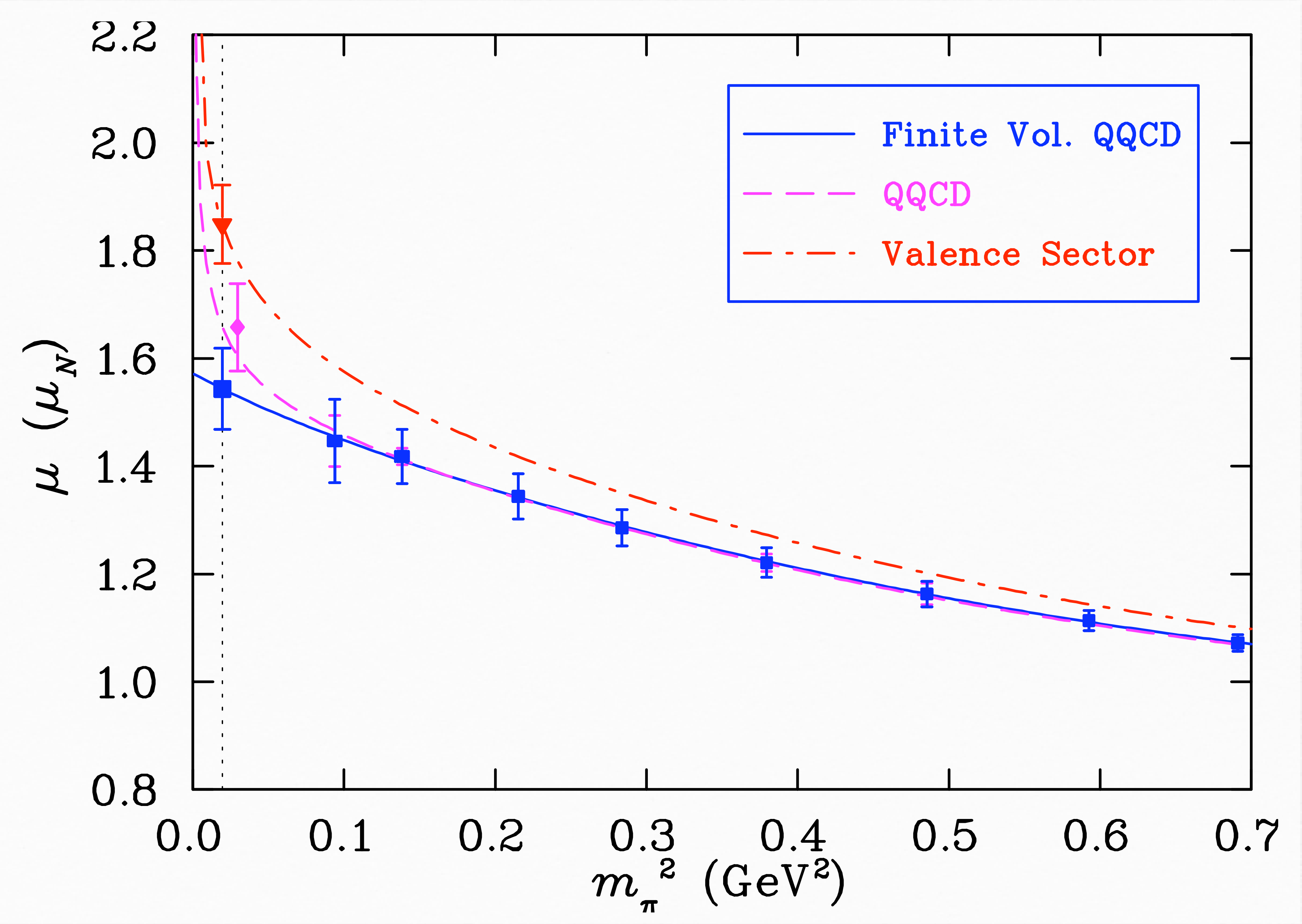
Constraint on GMs



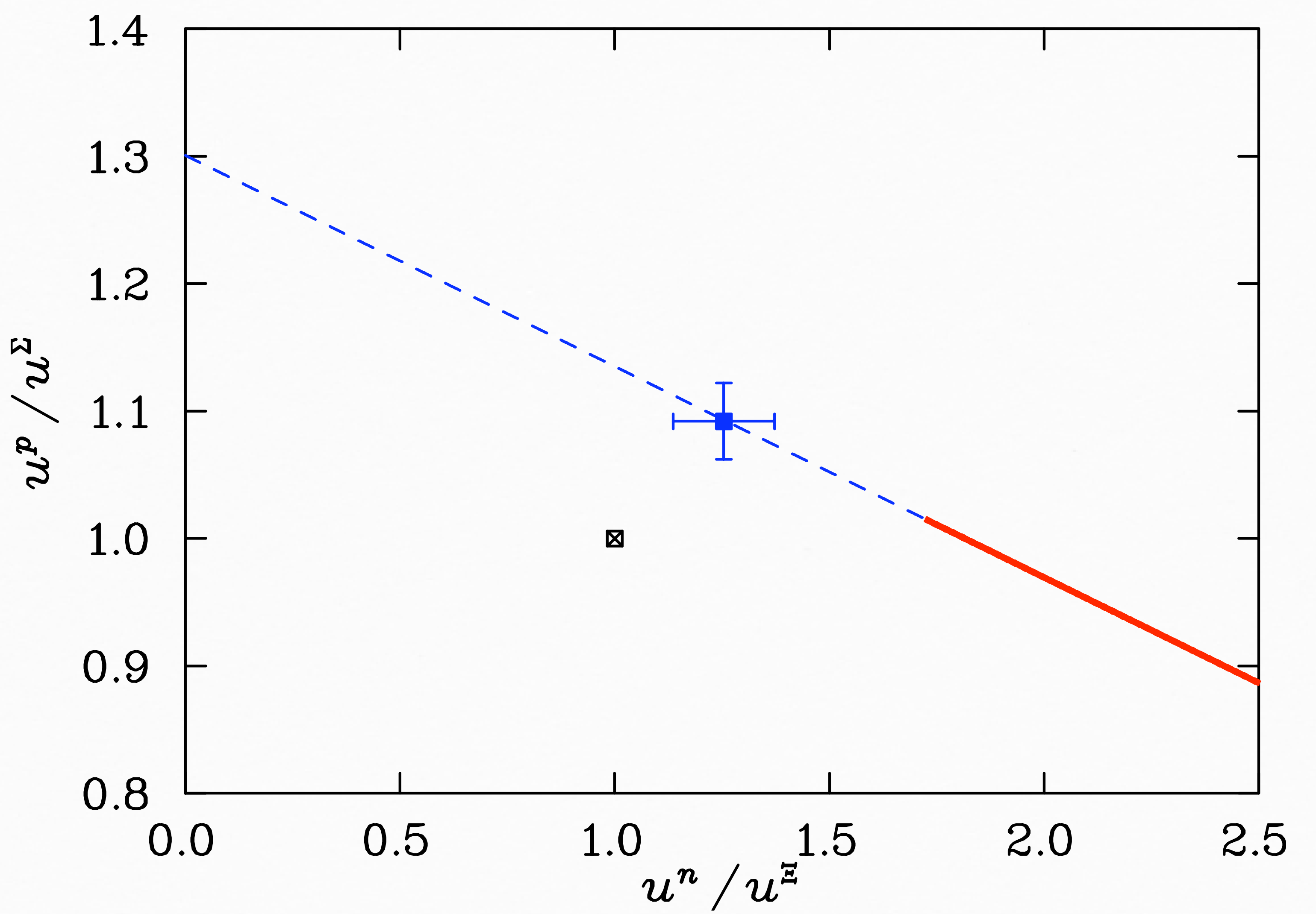
u-quark in proton



u-quark in Sigma



Almost There



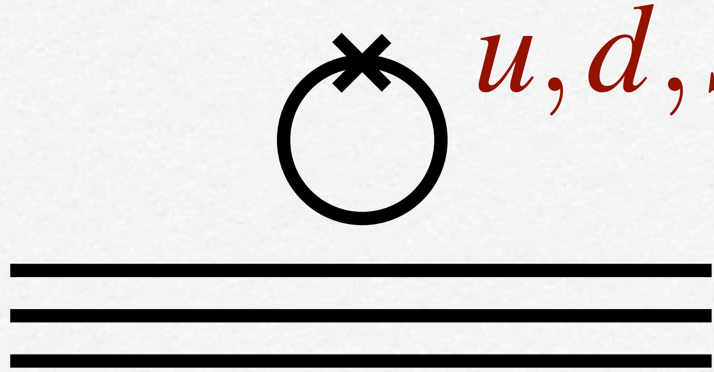
$$\frac{u^p}{u^\Sigma} = 1.092 \pm 0.030$$

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

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

Final Answer

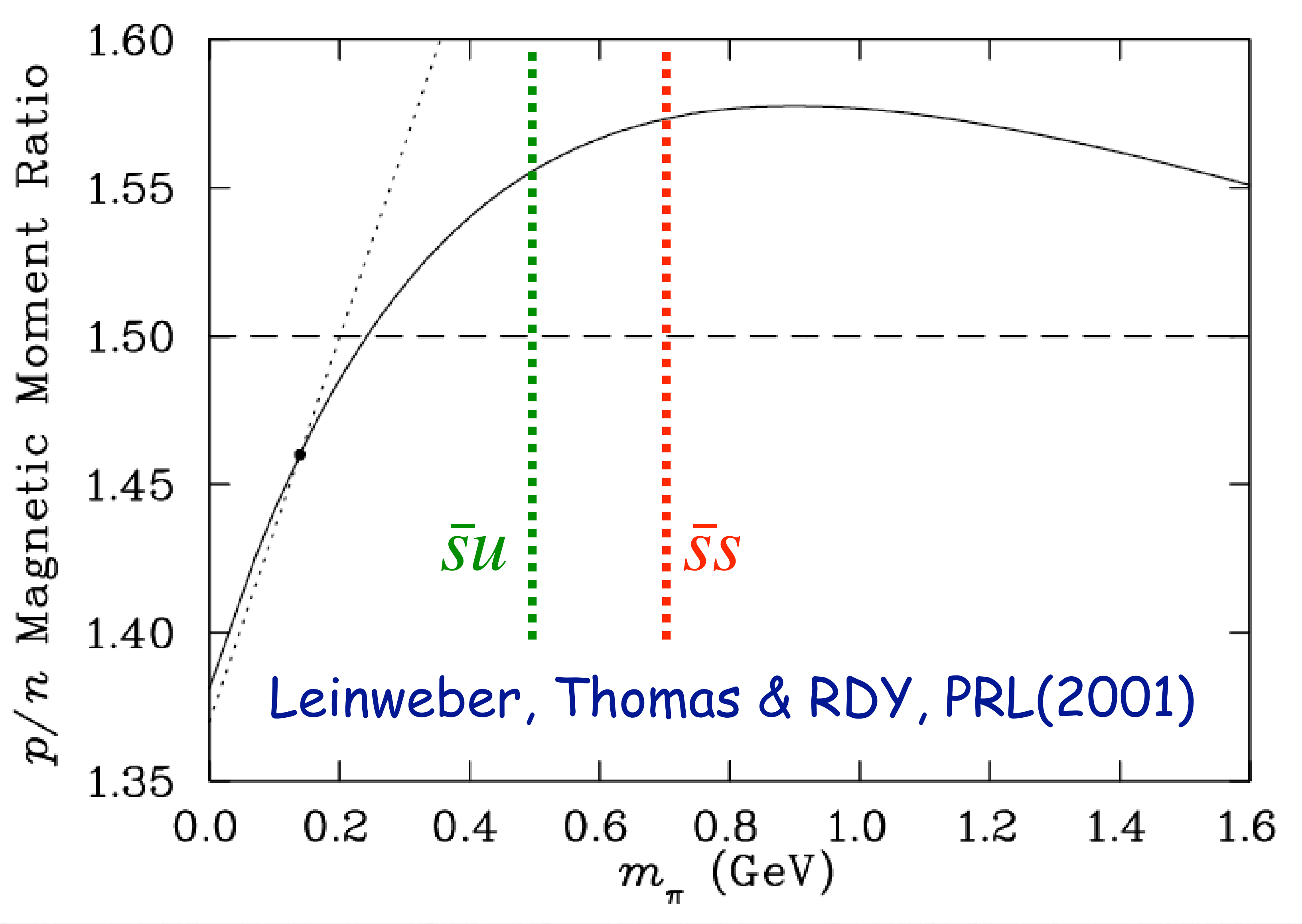
$$G_M^s = \left(\frac{{}^{l}R_d^s}{1 - {}^{l}R_d^s}\right)\left[2p + n - \frac{u^p}{u^\Sigma}(\Sigma^+ - \Sigma^-)\right]$$

$$G_M^s = \left(\frac{{}^{l}R_d^s}{1 - {}^{l}R_d^s}\right)\left[p + 2n - \frac{u^n}{u^\Xi}(\Xi^0 - \Xi^-)\right]$$

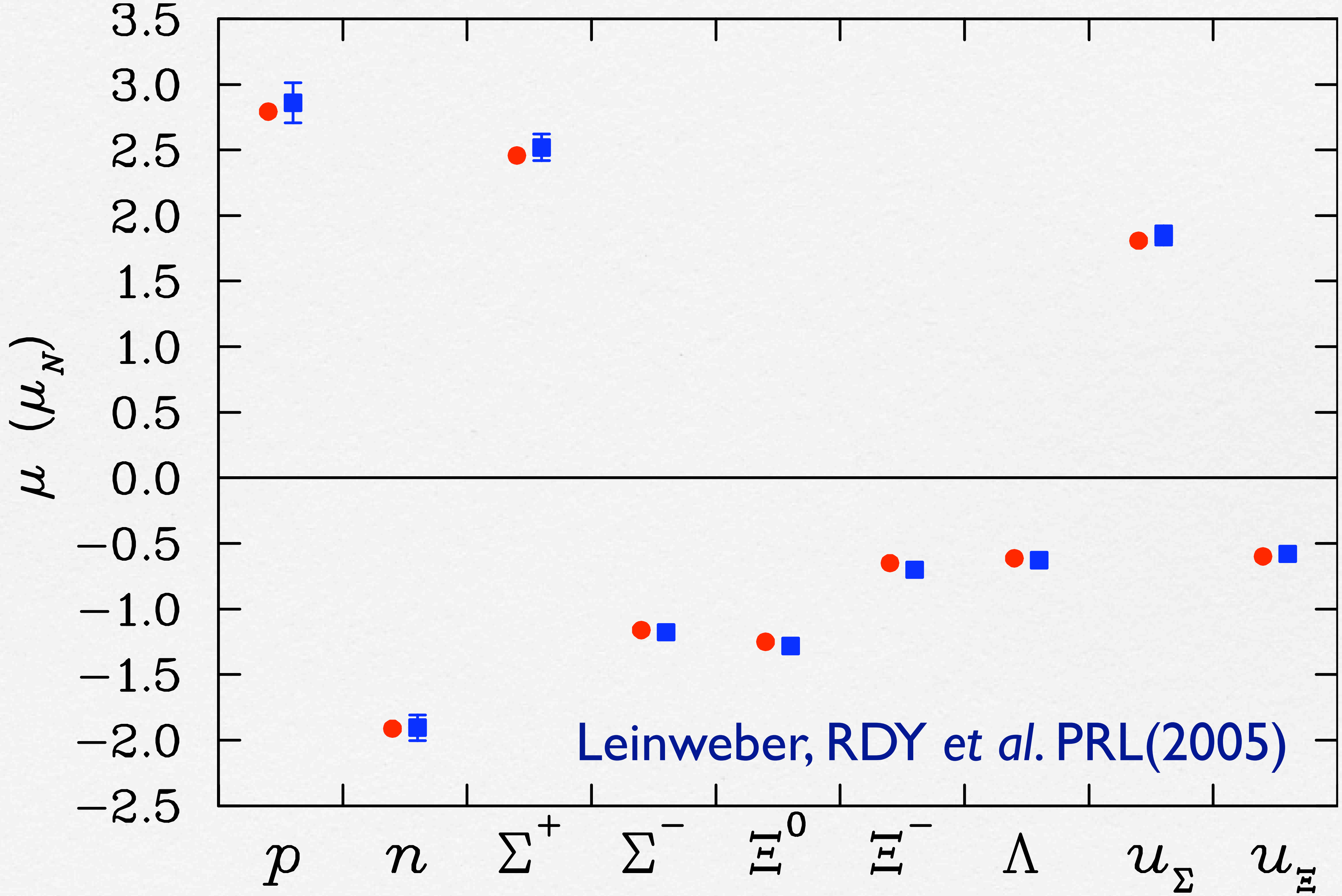
$$G_M^s = -0.046 \pm 0.022\,\mu_N$$

Is strange heavy?

- Heavy-quark EFT cannot create Goldstone kaon
- Heavy-quark limit: $\left|\frac{\mu_p}{\mu_n}\right| = \frac{3}{2}$

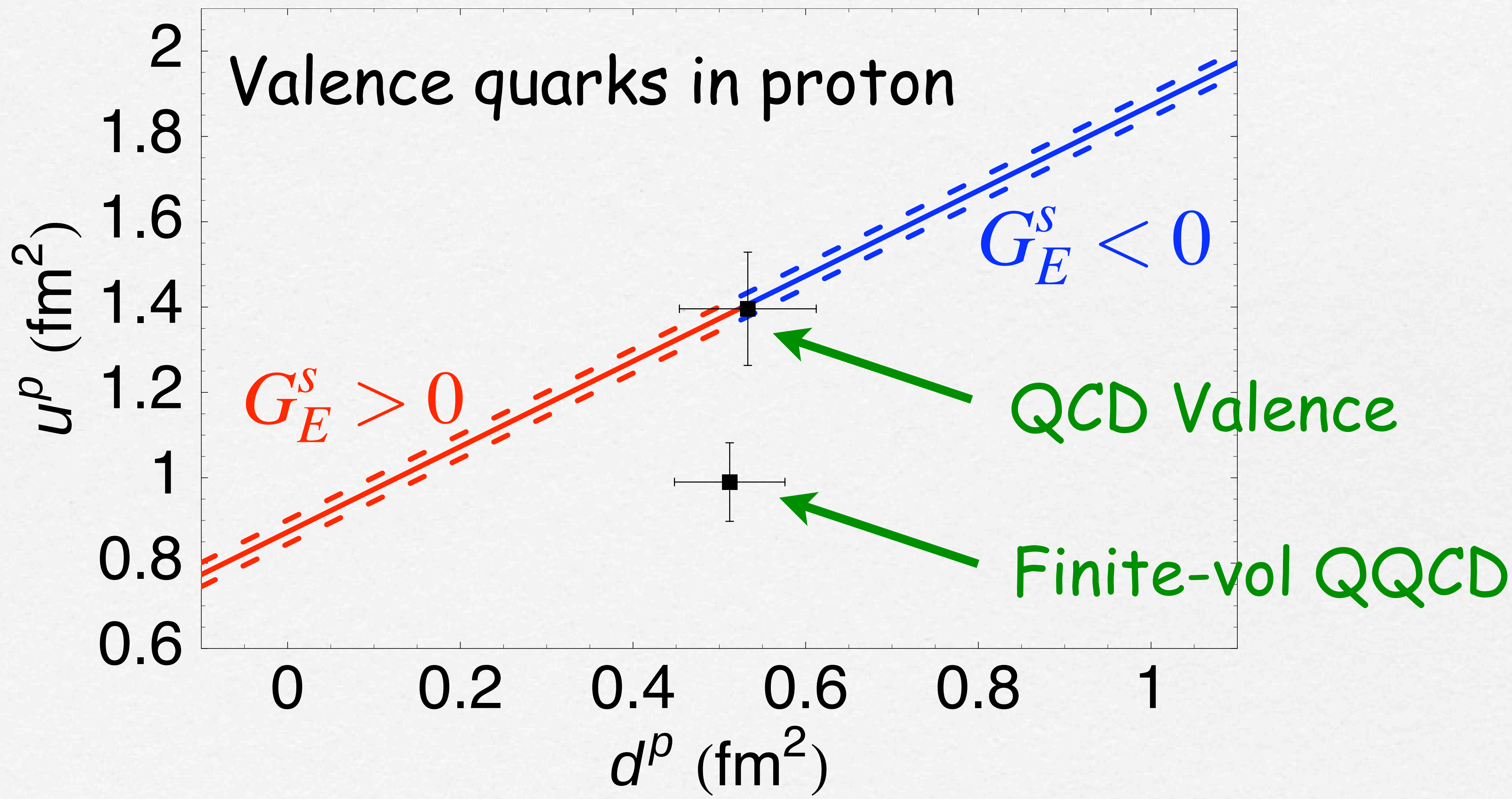


Octet Magnetic Moments



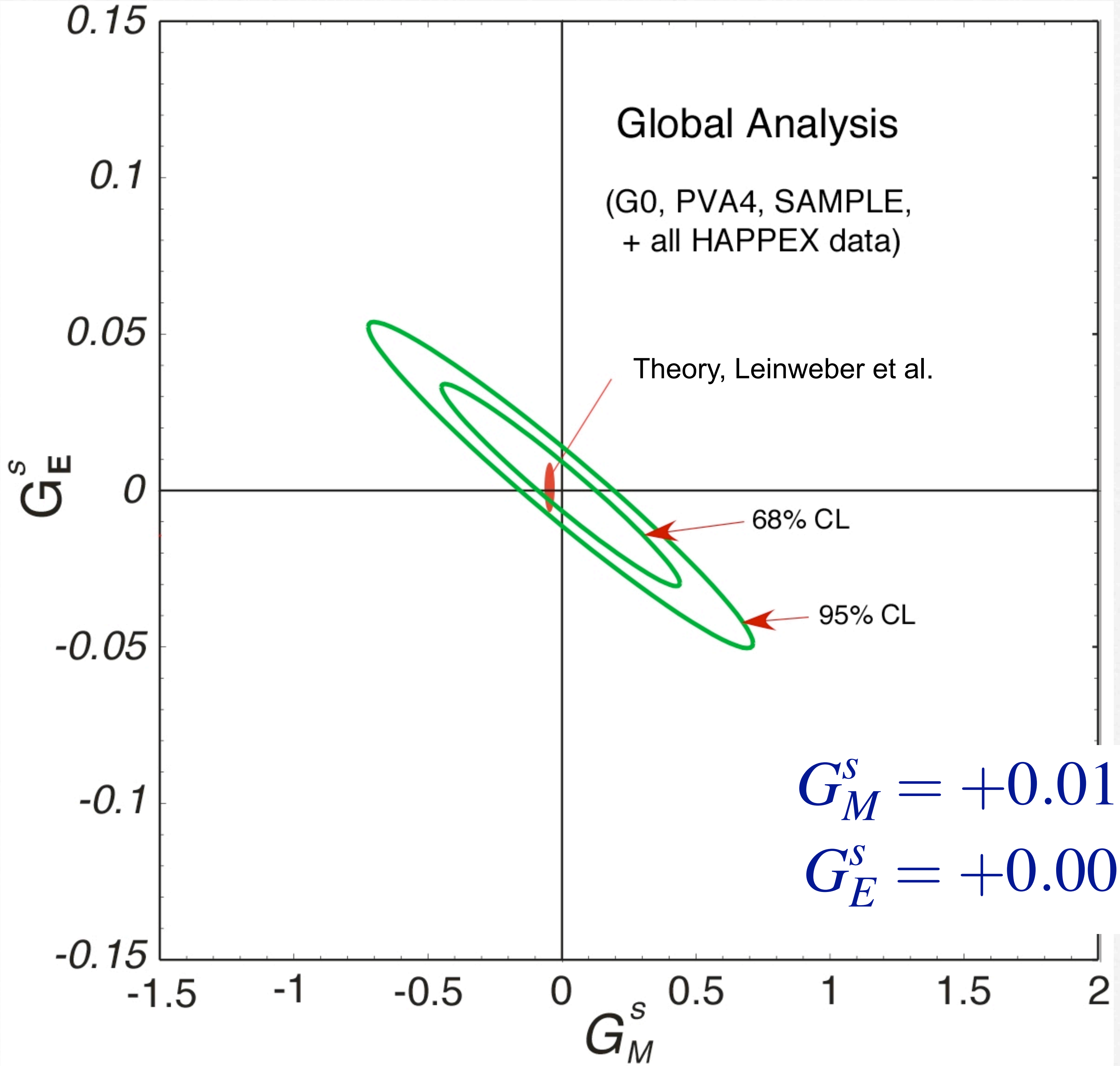
Repeat for electric radius

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



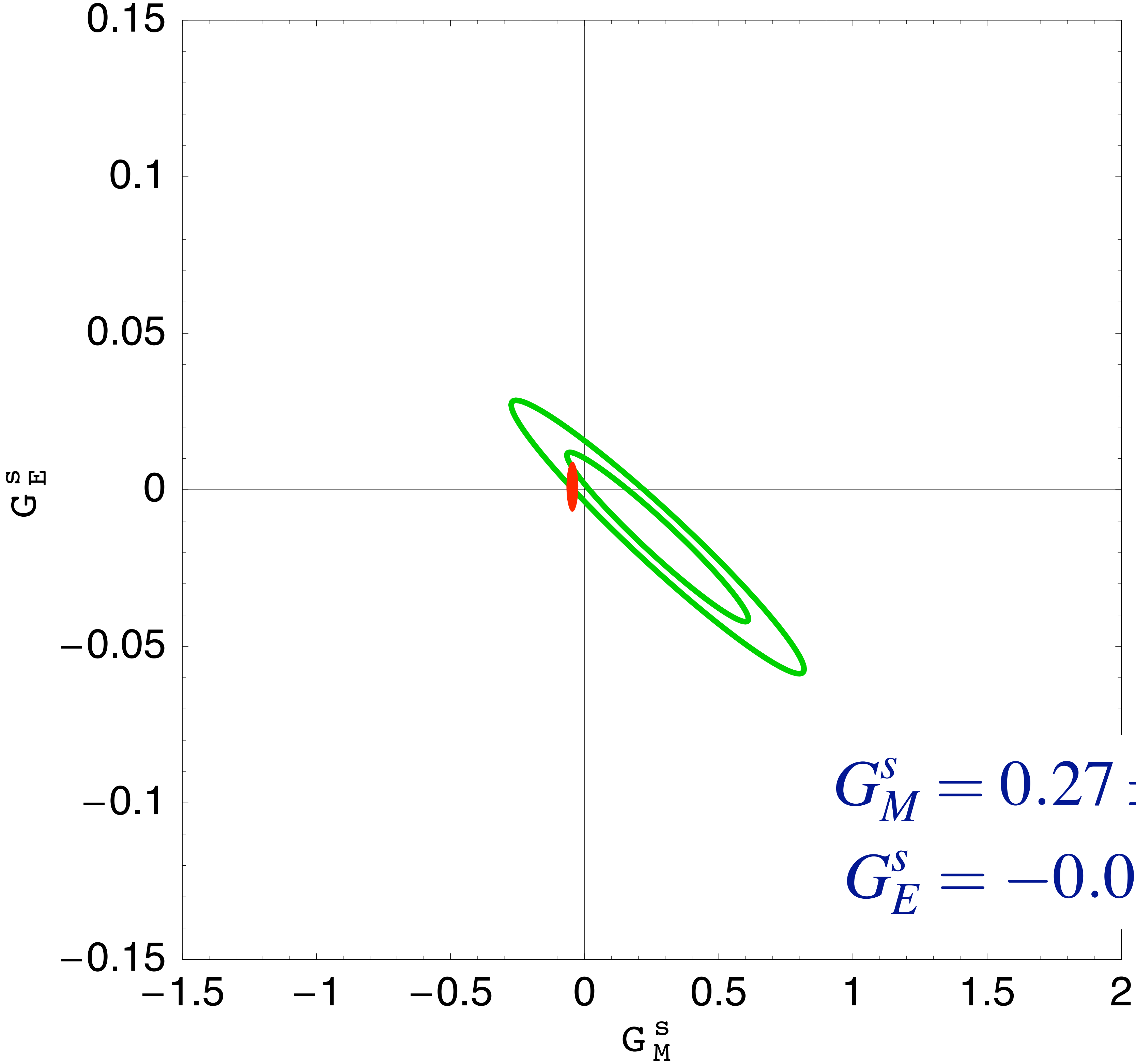
Experimental status:
All world data

$Q^2 < 0.3\,\mathrm{GeV}^2$

RDY et al. nucl-ex/0406010

+plus HAPPEx 2006

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



Experimental status:
All world data

$Q^2 < 0.3\,\mathrm{GeV}^2$

RDY et al. nucl-ex/0406010

+plus HAPPEx 2006

+anapole theory
Zhu et al. PRD(2000)

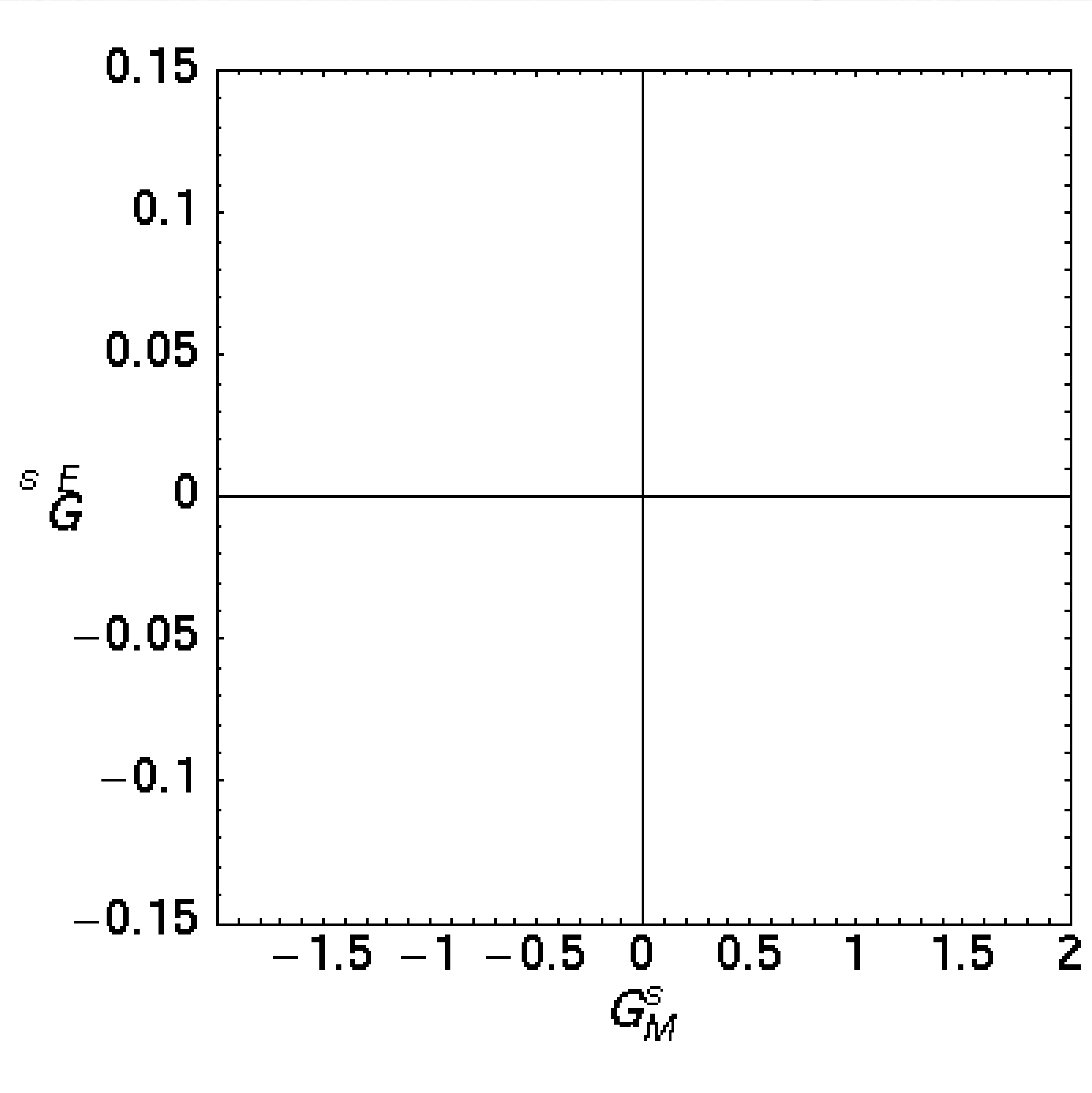
$$G_M^s = 0.27 \pm 0.22\,\mu_N$$
$$G_E^s = -0.015 \pm 0.018$$

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!



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HAPPEx

References

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Leinweber, RDY et al., hep-lat/0601025
RDY et al., nucl-ex/0604010 + all PVES expt