Strangeness in the Nucleon: Overview

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JLab Hall C 2005 Summer Workshop

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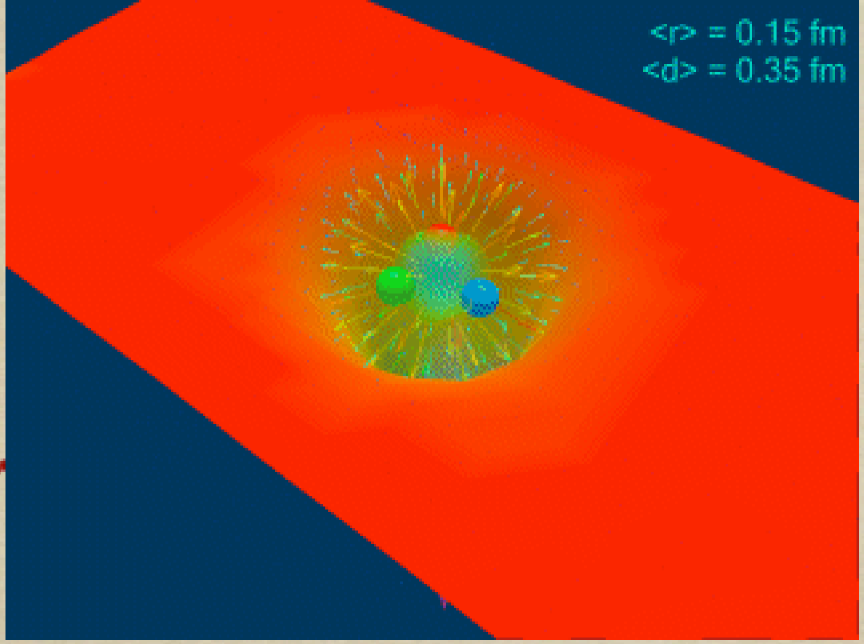
Strange Overview

- *Origins of mass:* $m_s\langle N|\bar{s}s|N\rangle$
- *Spin contributions* Δs
- *Electromagnetic currents:* G_E^s & G_M^s
- *Lattice calculation*

Origins of mass



Leinweber *et al.*

$m_q \sim 5\,\mathrm{MeV}$

$m_N \sim 940\,\mathrm{MeV}$

- *Mass dynamically generated by quark-gluon interactions*
- *What is the role of strange quarks?*

Gell-Mann–Okubo relation $M_N, M_\Lambda, M_\Sigma, M_\Xi$

$$m_s\langle N|\bar{s}s|N\rangle \simeq 335 \pm 132\,\mathrm{MeV}$$

Nelson & Kaplan PLB(1987)

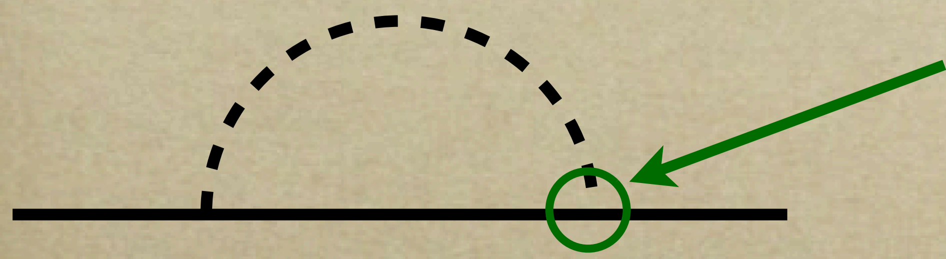
measures $\sim M_N^{phys} - M_N^{SU(3) chiral\ limit}$

QCD Lagrangian $\sim \ldots \bar{s}(\not{D} + m_s)s$

$$m_s\langle N|\bar{s}s|N\rangle = m_s \frac{\partial M_N}{\partial m_s}$$

evaluated at physical point!

Chiral Perturbation Theory



KNOWN: Low-energy behaviour

UNKNOWN: Short distance effects

Low-energy constants

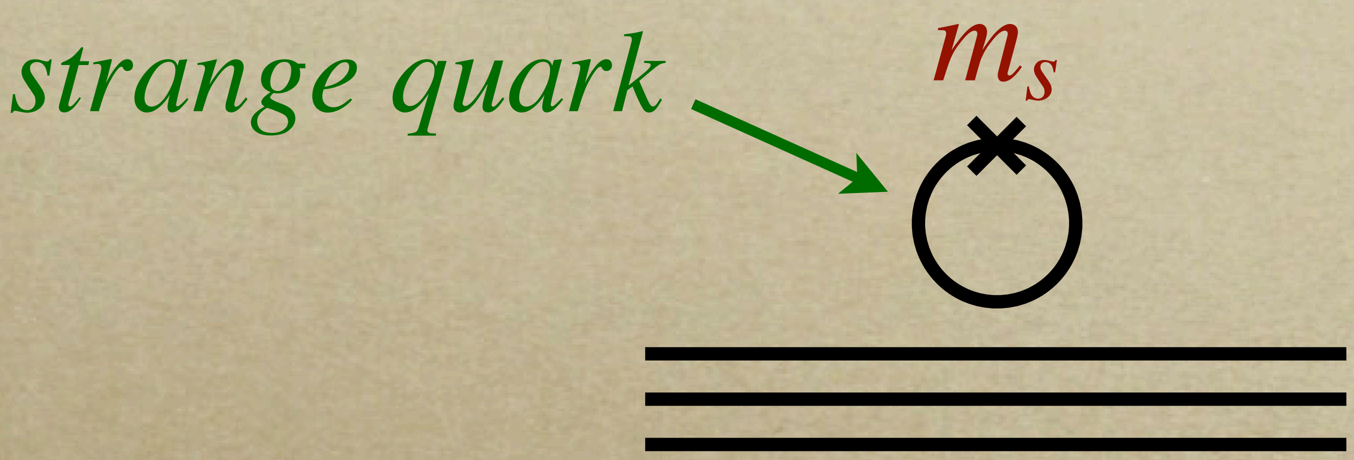
Borasoy & Meissner (1997)

High-order calculation

$$m_s \frac{\partial M_N}{\partial m_s} = 113 \pm 108\,\text{MeV}$$

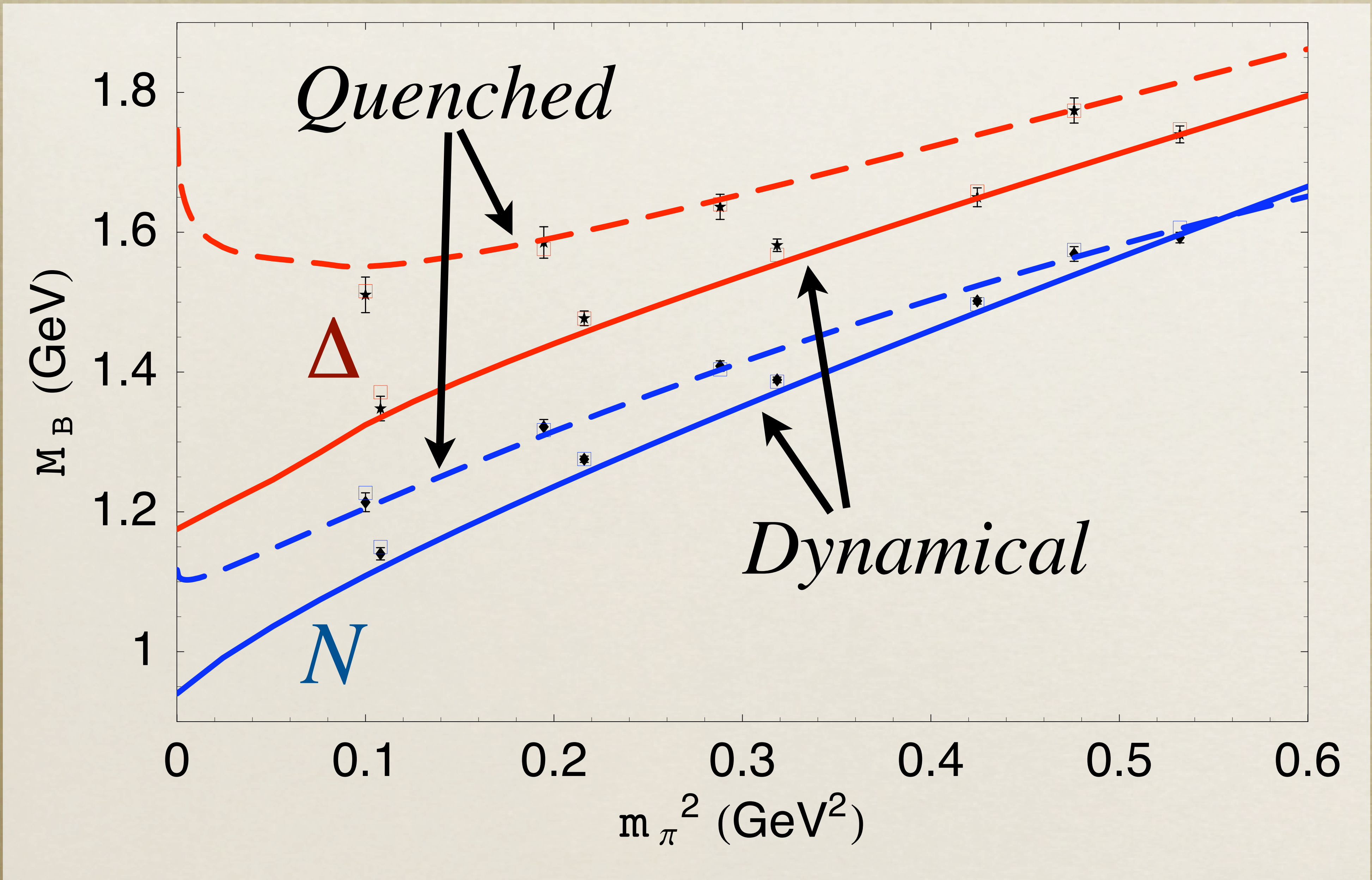
Resonance saturation MODEL to determine UNKNOWN!

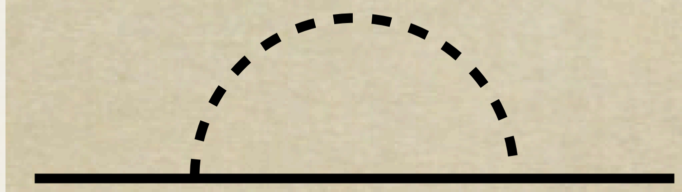
Strange Loops



- *What is the correction to the nucleon mass from this loop?*
- *Chiral phenomenology, excellent description of loop effects*

Lattice Results

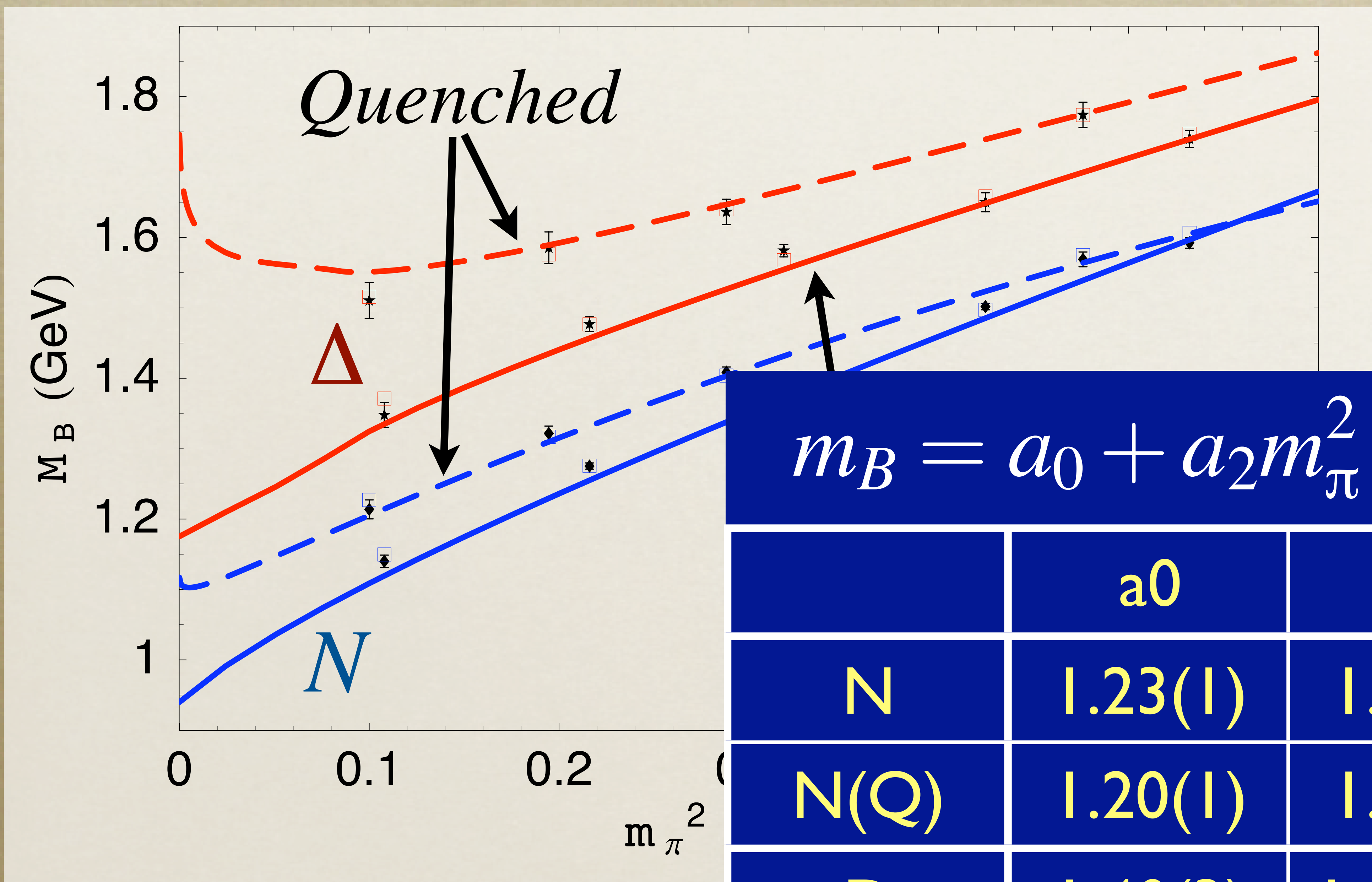




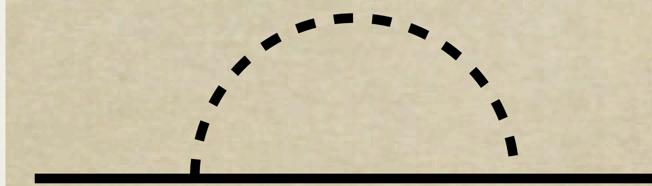
Differences described by chiral loops

RDY *et al.* PRD(2002)

Lattice Results



RDY *et al.* PRD(2002)

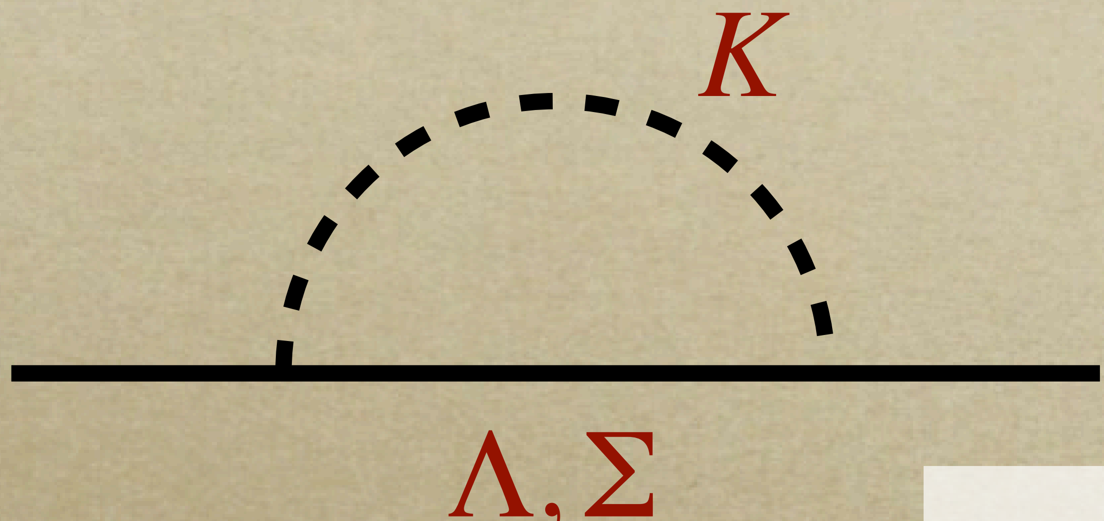


Differences

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

	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)

Modelling Strangeness



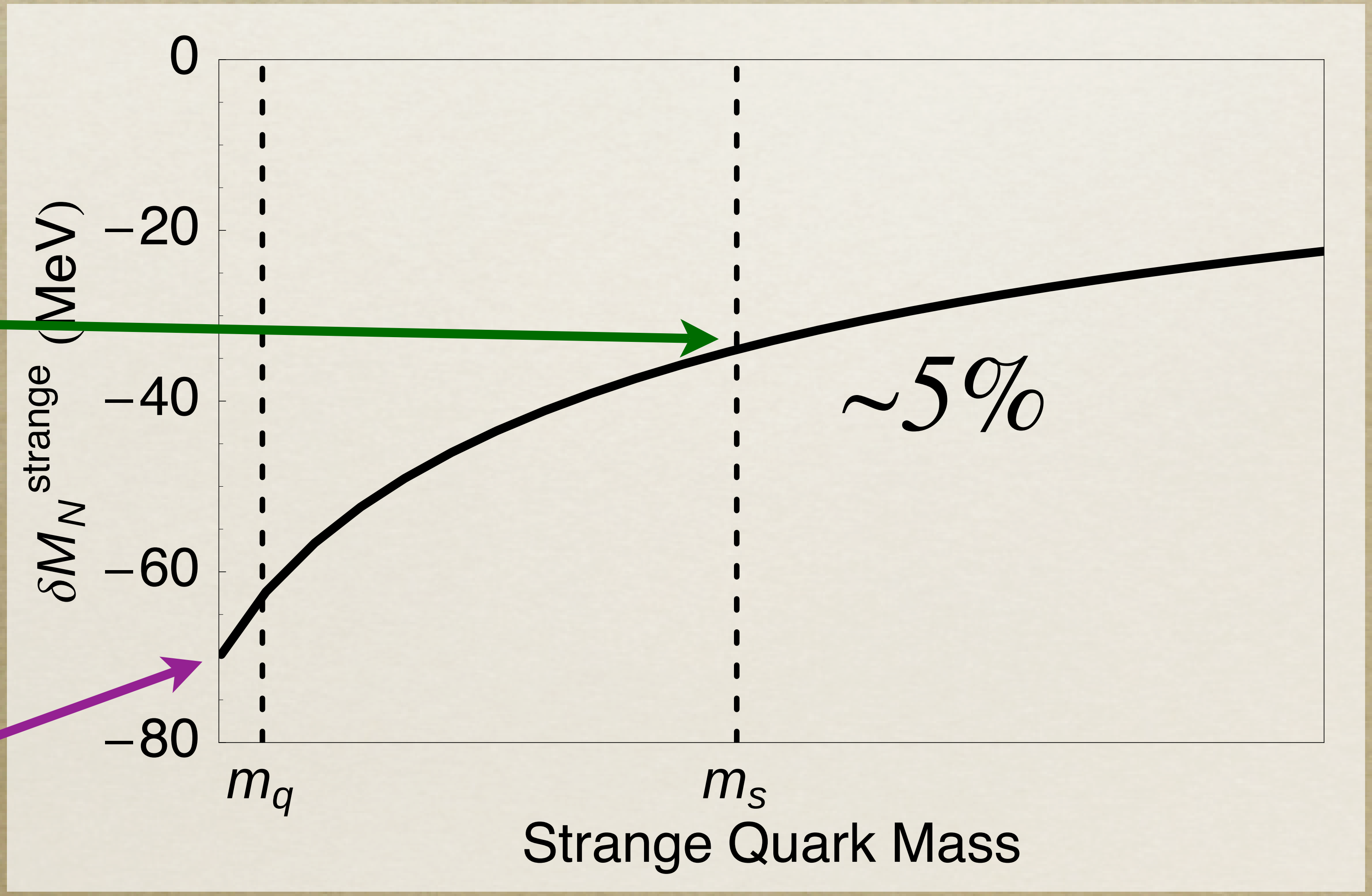
Dominant strange contributions in Kaon cloud

$$m_s \langle N | \bar{s}s | N \rangle$$

Local derivative

$$m_s \frac{\partial M_N}{\partial m_s} \simeq 16\,\mathrm{MeV}$$

$$\sim 110\,\mathrm{MeV}$$



Strange spin content

Polarised deep-inelastic scattering

$$\int dx\, g_1(x)$$

axial charge g_A

hyperon decay $3F - D$

$$\Delta s = -0.10 \pm 0.04$$

Bass (2004)

Semi-inclusive reactions

$$\Delta s = 0.028 \pm 0.033 \pm 0.009$$

over measured range

HERMES PRD(2005)

Electromagnetic Structure

Strange form factors G_E^s & G_M^s

- **Hot topic:**
  SAMPLE, HAPPEX, MAINZ/A4, G0
- *Parity-violating electron scattering (PVES)*
- *Elastic form factor measurements with polarised electron beam*

PV asymmetry

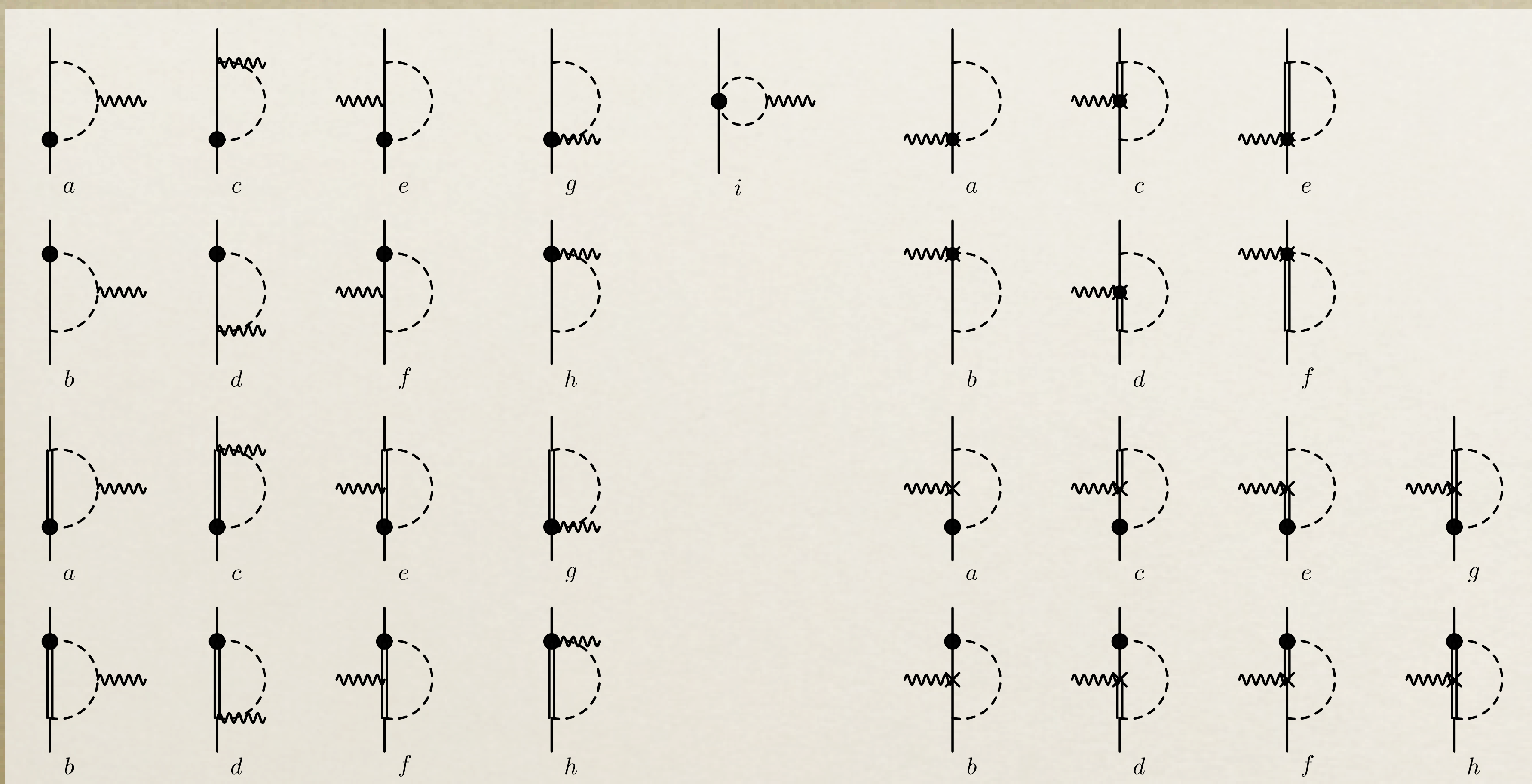
Interference between γ and Z probes

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

Strangeness

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

Calculation of Anapole Moment

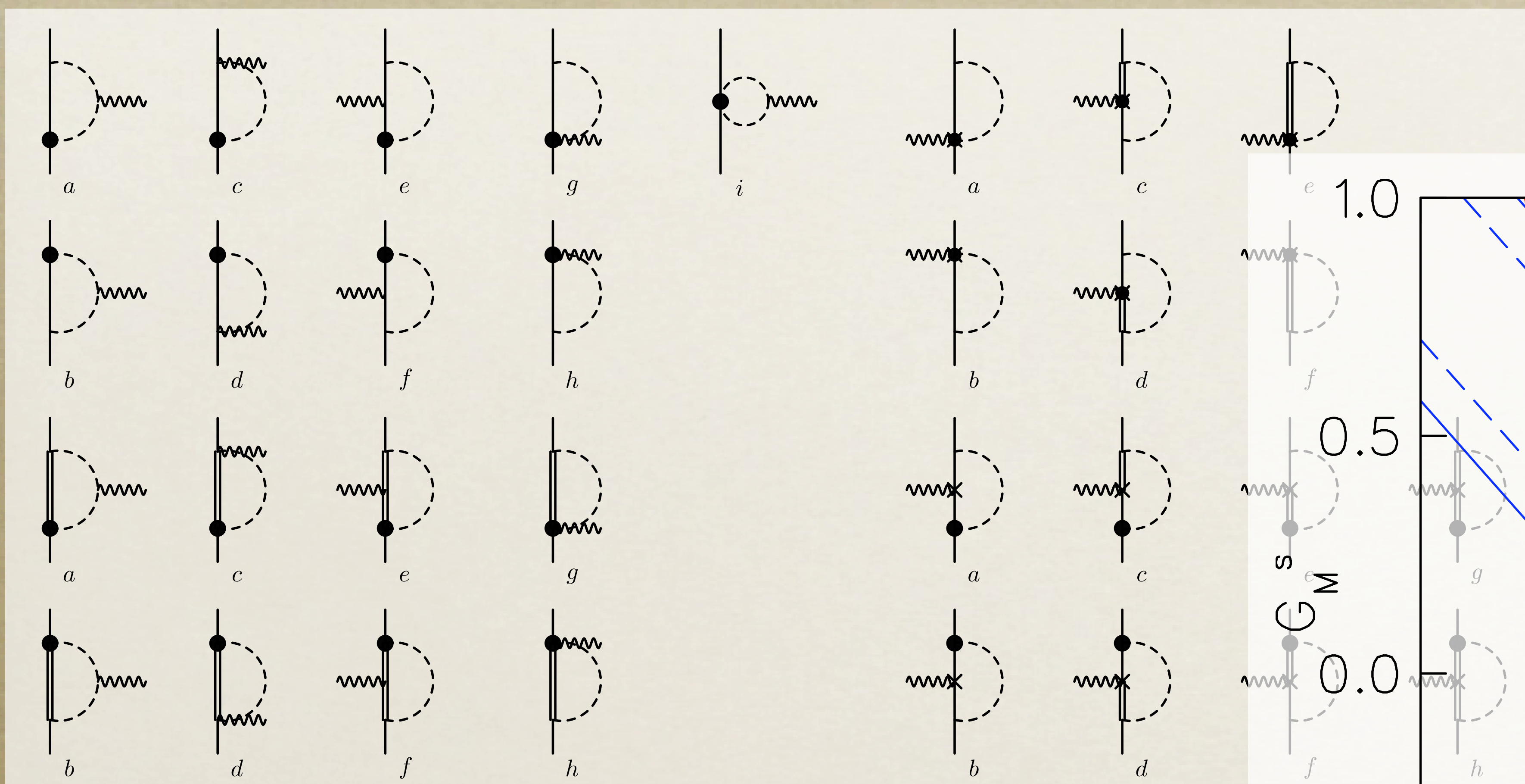


Zhu *et al.* PRD(2000)

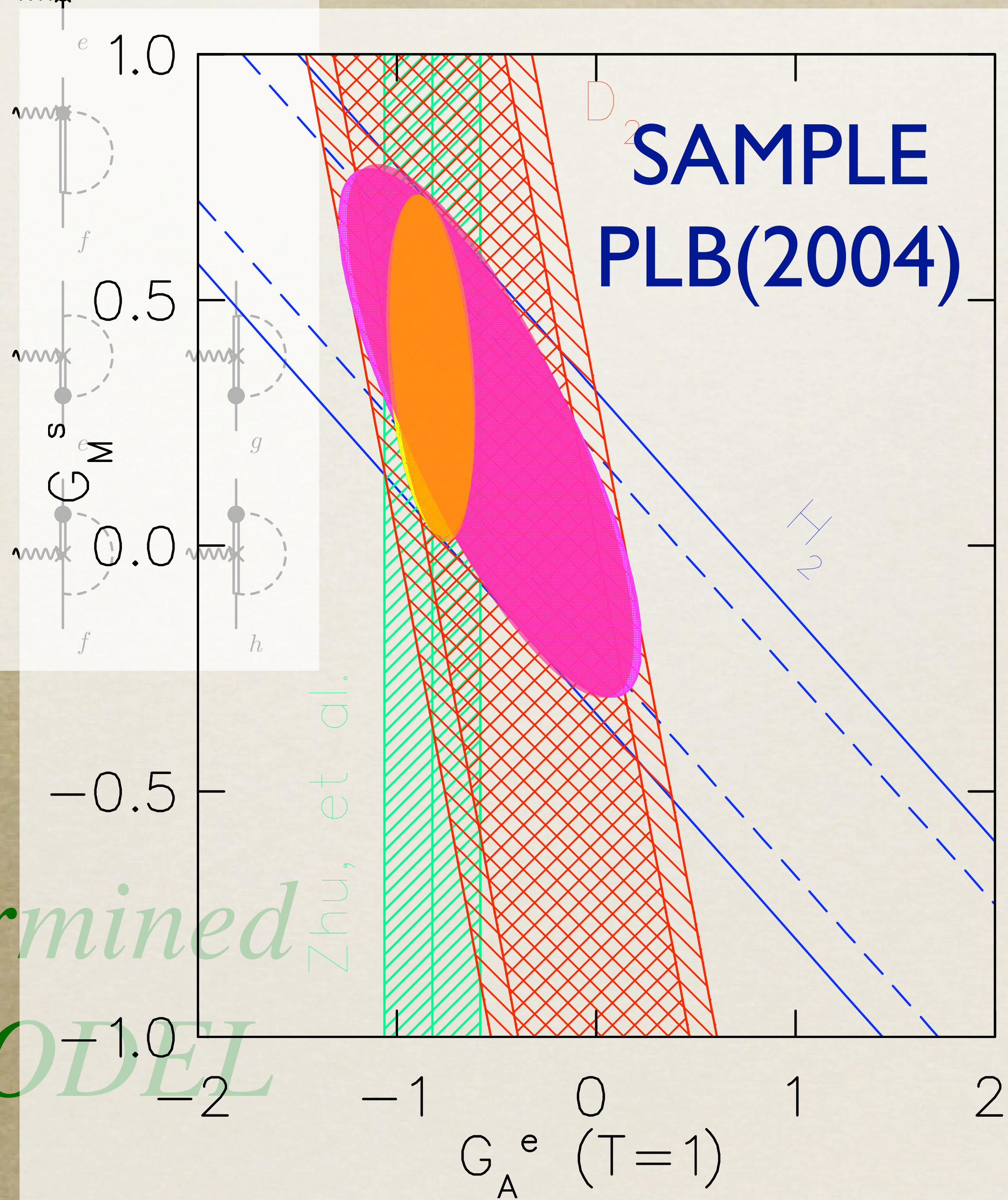
Chiral perturbation theory

Low-energy constants determined by resonance saturation MODEL

Calculation of Anapole Moment



Zhu *et al.* PRD(2000)



SAMPLE PLB(2004)

Chiral perturbation theory

Low-energy constants determined by resonance saturation MODEL

Lattice Results

Dong *et al.* PRD(1998) $G_M^s = -0.36 \pm 0.20$

Mathur & Dong NPB(2001) $G_M^s = -0.27 \pm 0.10$

Lewis *et al.* PRD(2003) $G_M^s(0.1\,\mathrm{GeV}^2) = +0.05 \pm 0.06$

Leinweber *et al.* PRL(2005) $G_M^s = -0.046 \pm 0.019$

Charge Symmetry Constraint

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

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

Lattice QCD

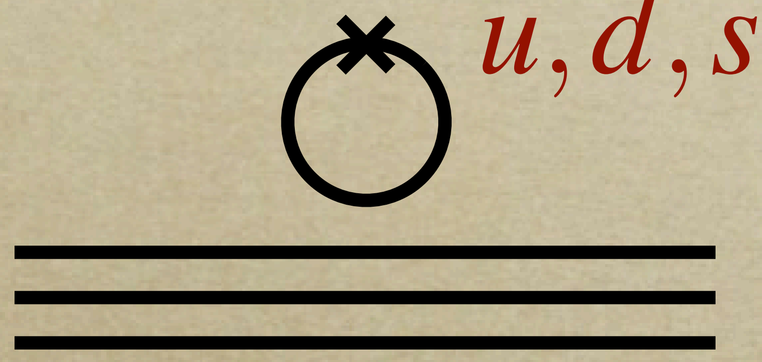
$$\Sigma^+ = \frac{2}{3}u^\Sigma - \frac{1}{3}s^\Sigma + O_\Sigma$$
$$\Sigma^- = -\frac{1}{3}u^\Sigma - \frac{1}{3}s^\Sigma + O_\Sigma$$

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

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

Disconnected Loops

$$O_N =$$



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

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

QCD equality for $m_u = m_d$

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

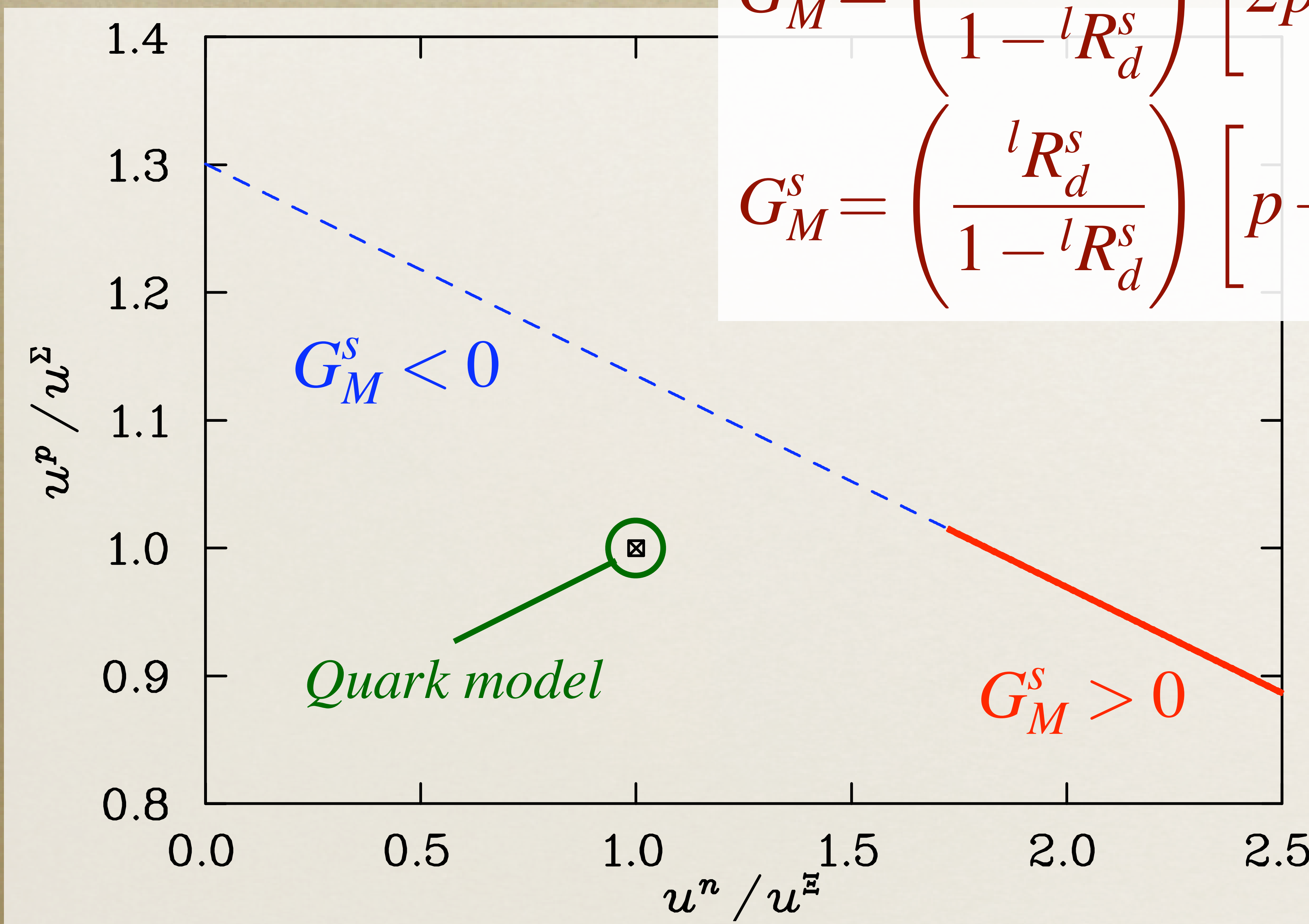
$$= \frac{{}^{l}G_M^s}{3}\left(\frac{1 - {}^{l}R_d^s}{{}^{l}R_d^s}\right)$$

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

Constraint on GMs

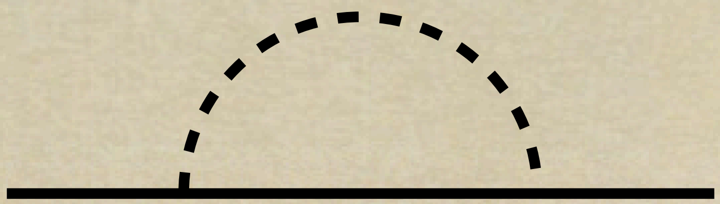
$$G_M^s = \left(\frac{{}^l R_d^s}{1 - {}^l R_d^s}\right)\left[2p + n - \frac{u^p}{u^\Sigma}(\Sigma^+ - \Sigma^-)\right]$$

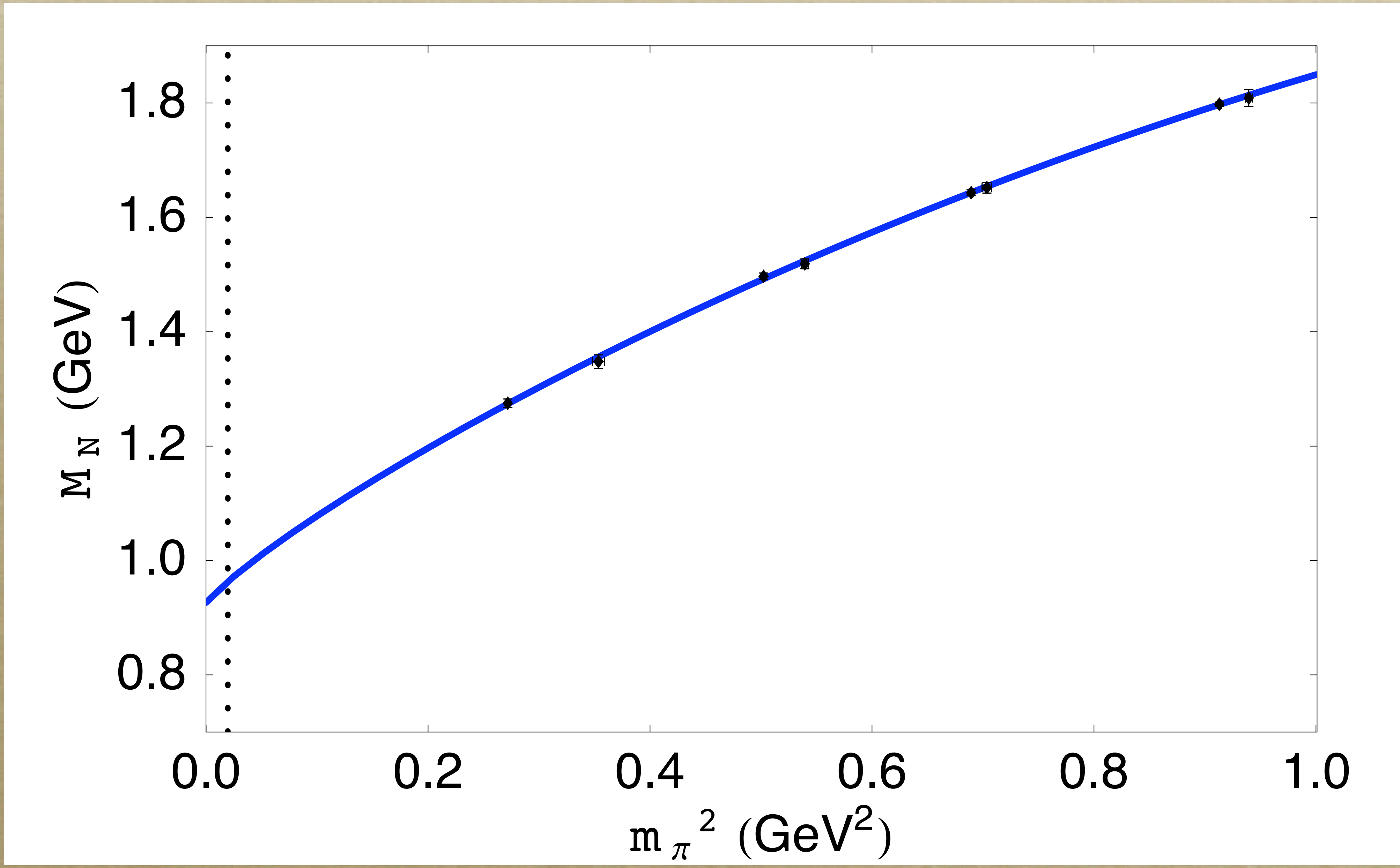
$$G_M^s = \left(\frac{{}^l R_d^s}{1 - {}^l R_d^s}\right)\left[p + 2n - \frac{u^n}{u^\Xi}(\Xi^0 - \Xi^-)\right]$$



Lattice QCD

Chiral Extrapolation

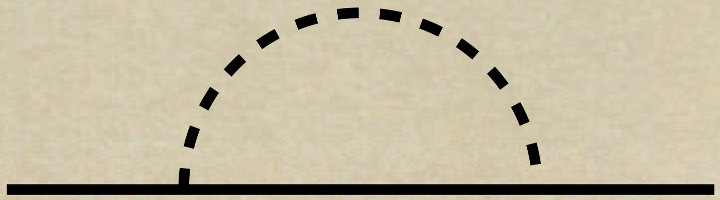


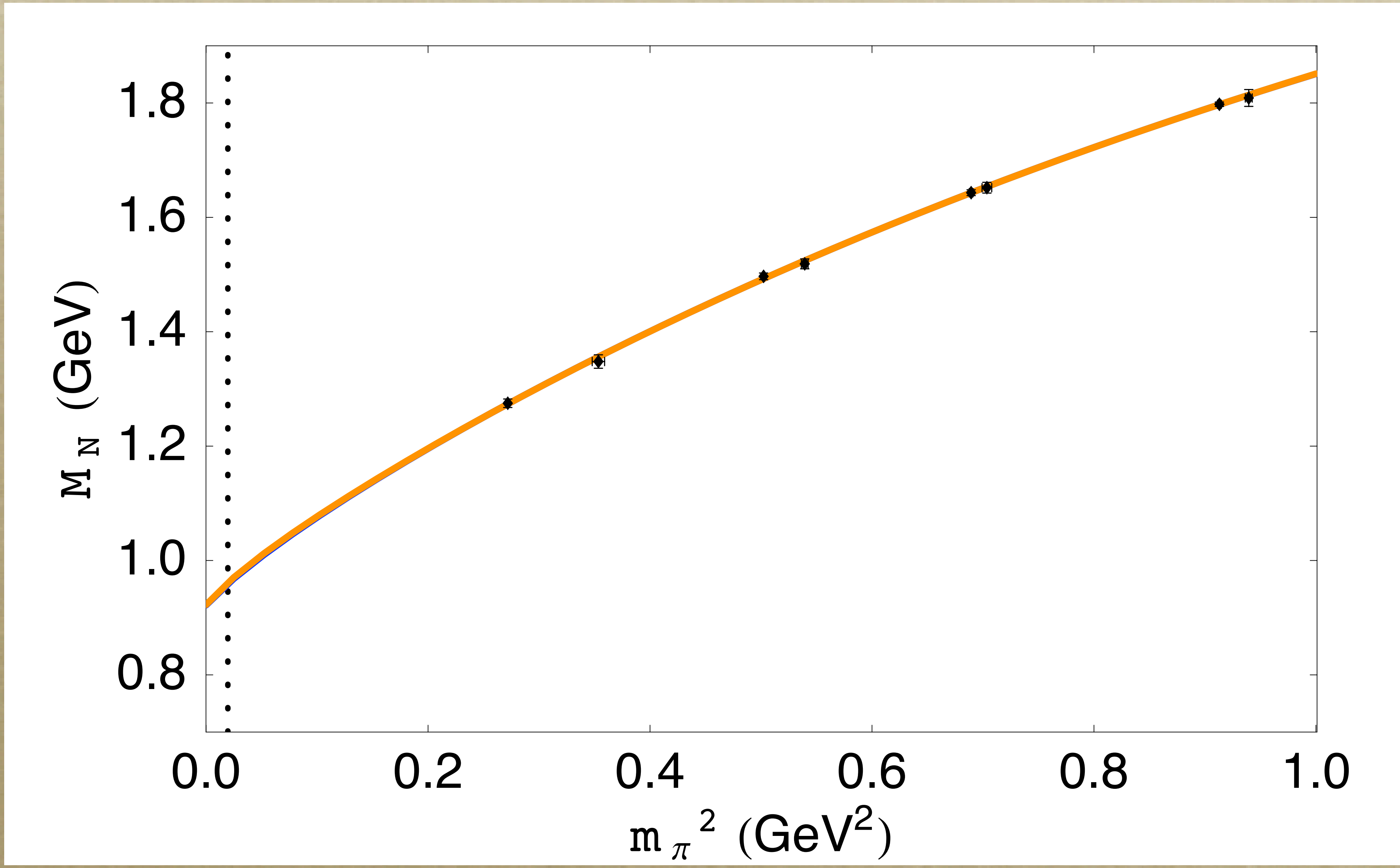


Dipole

Leinweber, Thomas & RDY PRL(2004)

Chiral Extrapolation



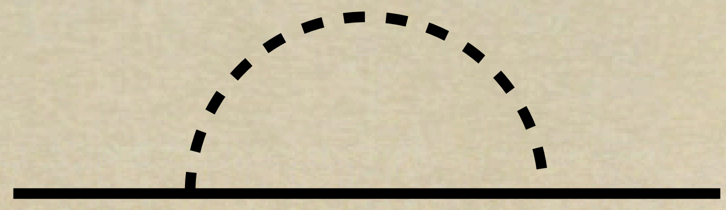


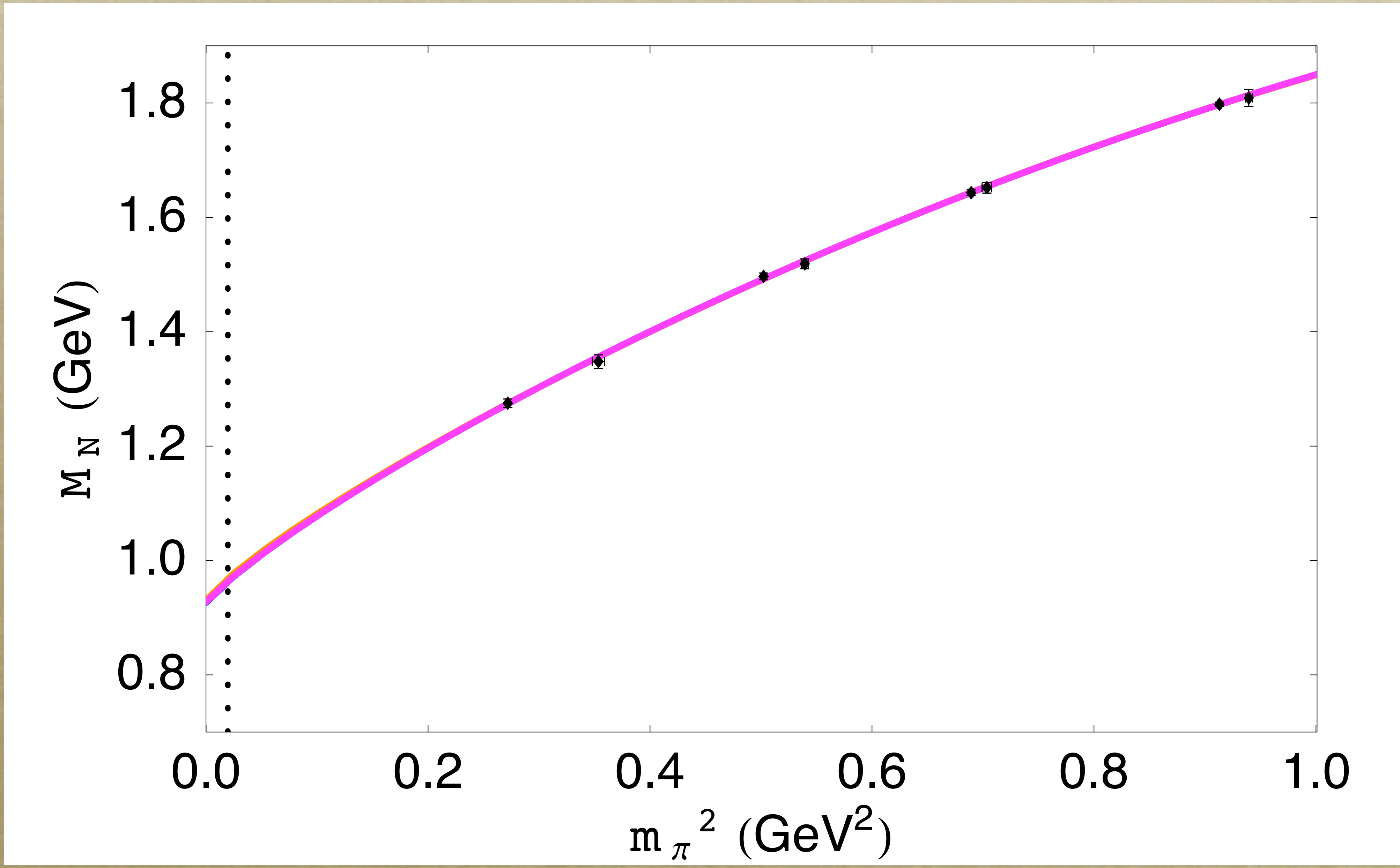
Dipole

Theta

Leinweber, Thomas & RDY PRL(2004)

Chiral Extrapolation





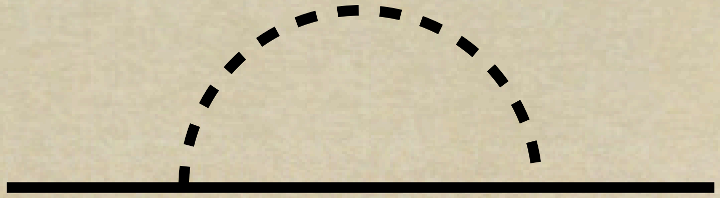
Dipole

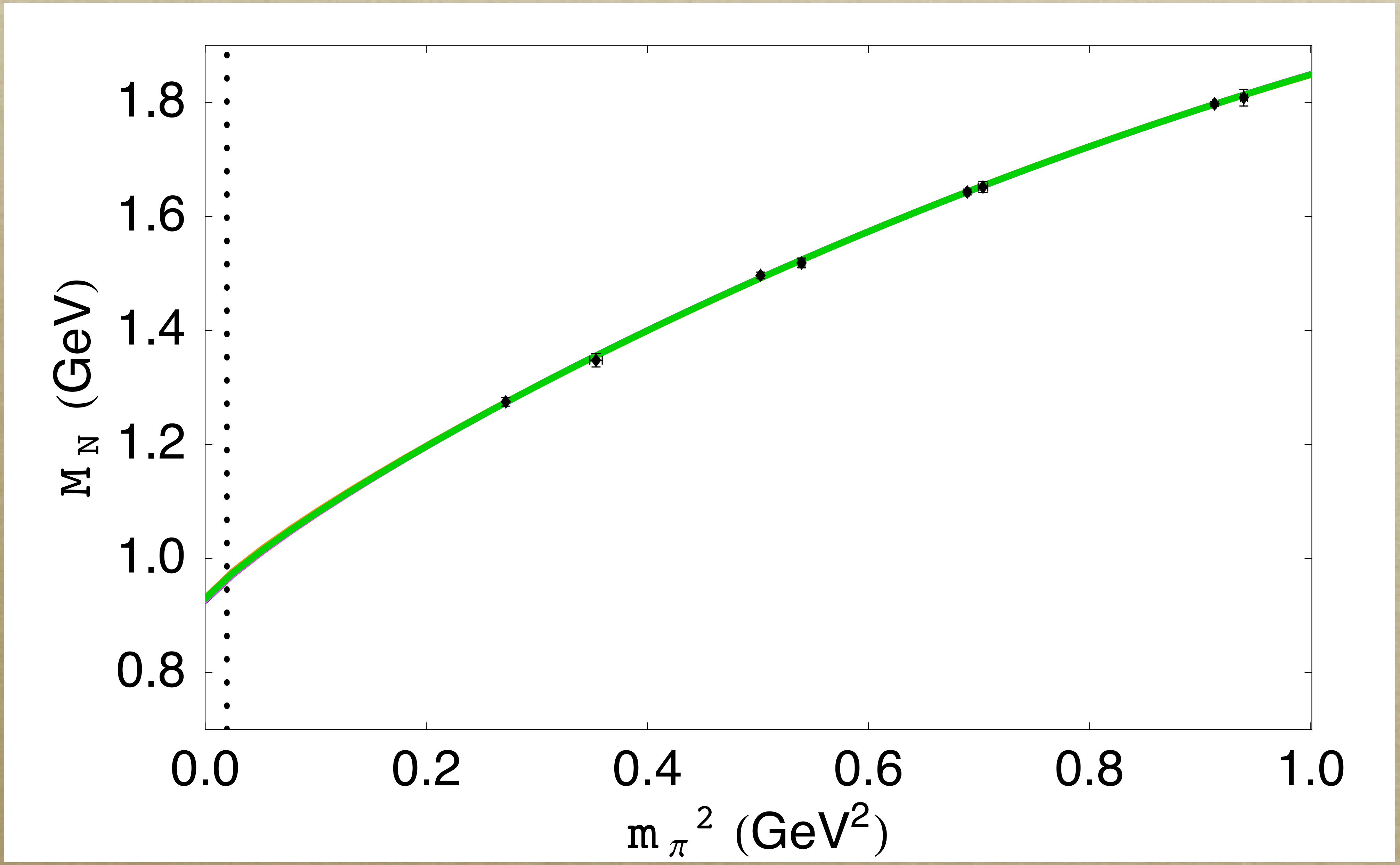
Theta

Monopole

Leinweber, Thomas & RDY PRL(2004)

Chiral Extrapolation





Dipole

Theta

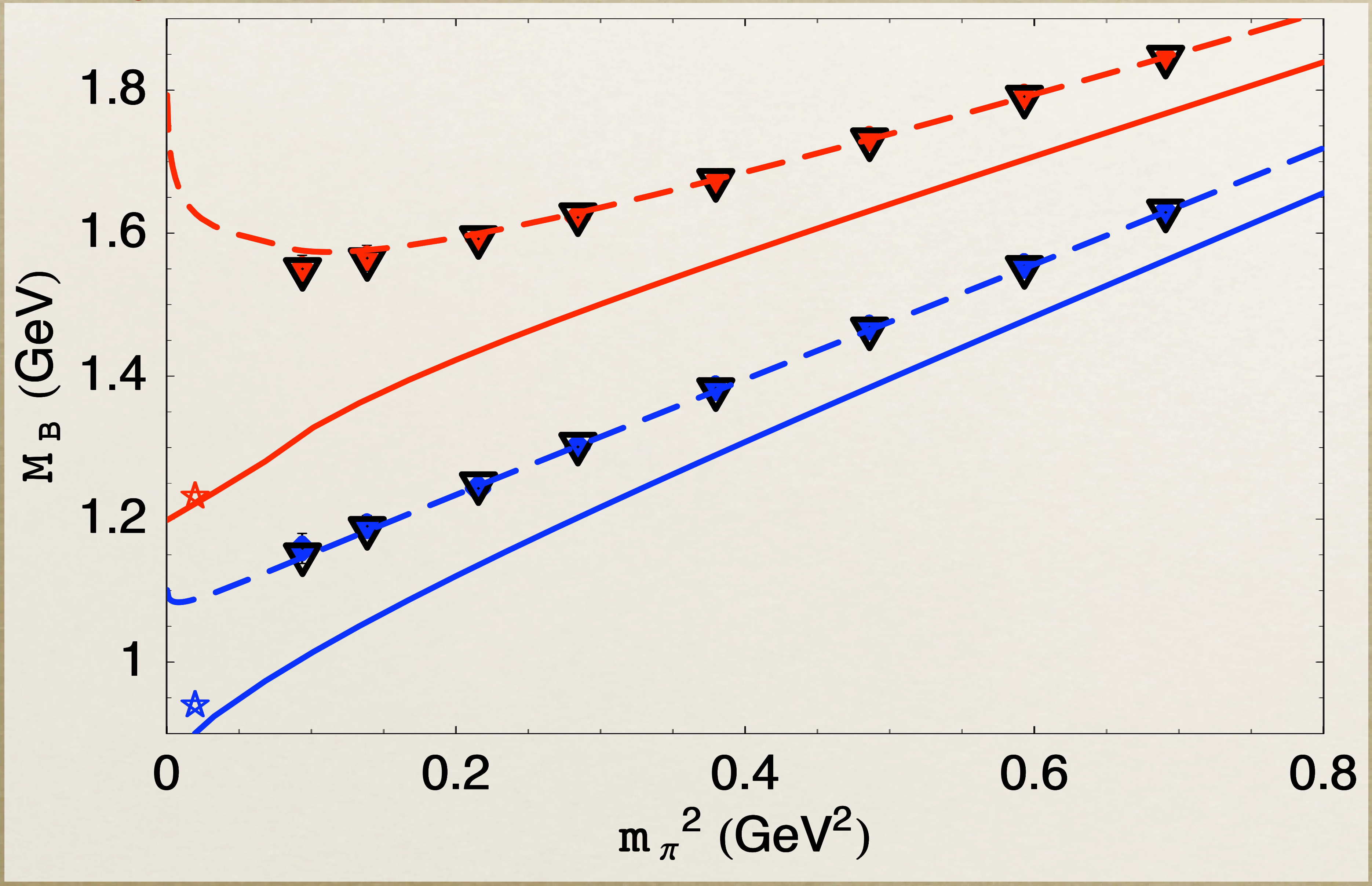
Monopole

Gaussian

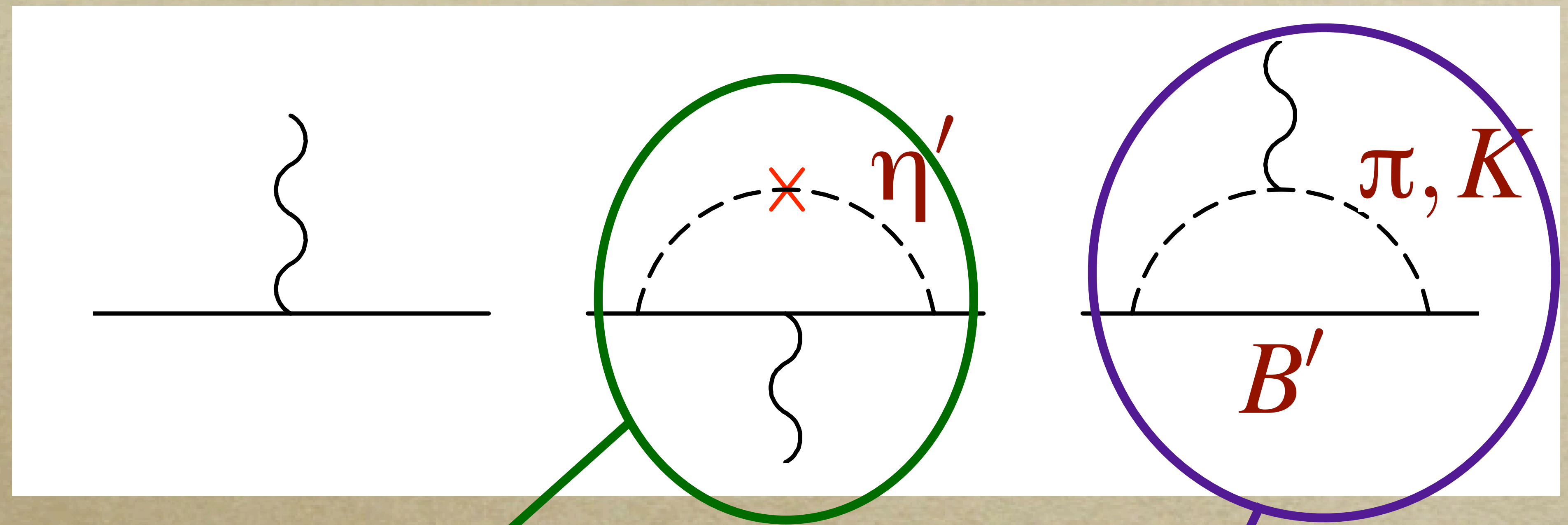
Leinweber, Thomas & RDY PRL(2004)

Quenched Approximation

$$\langle \hat{O} \rangle = \int DU\, \hat{O}\, \det M[U] \exp(-S_G[U])$$



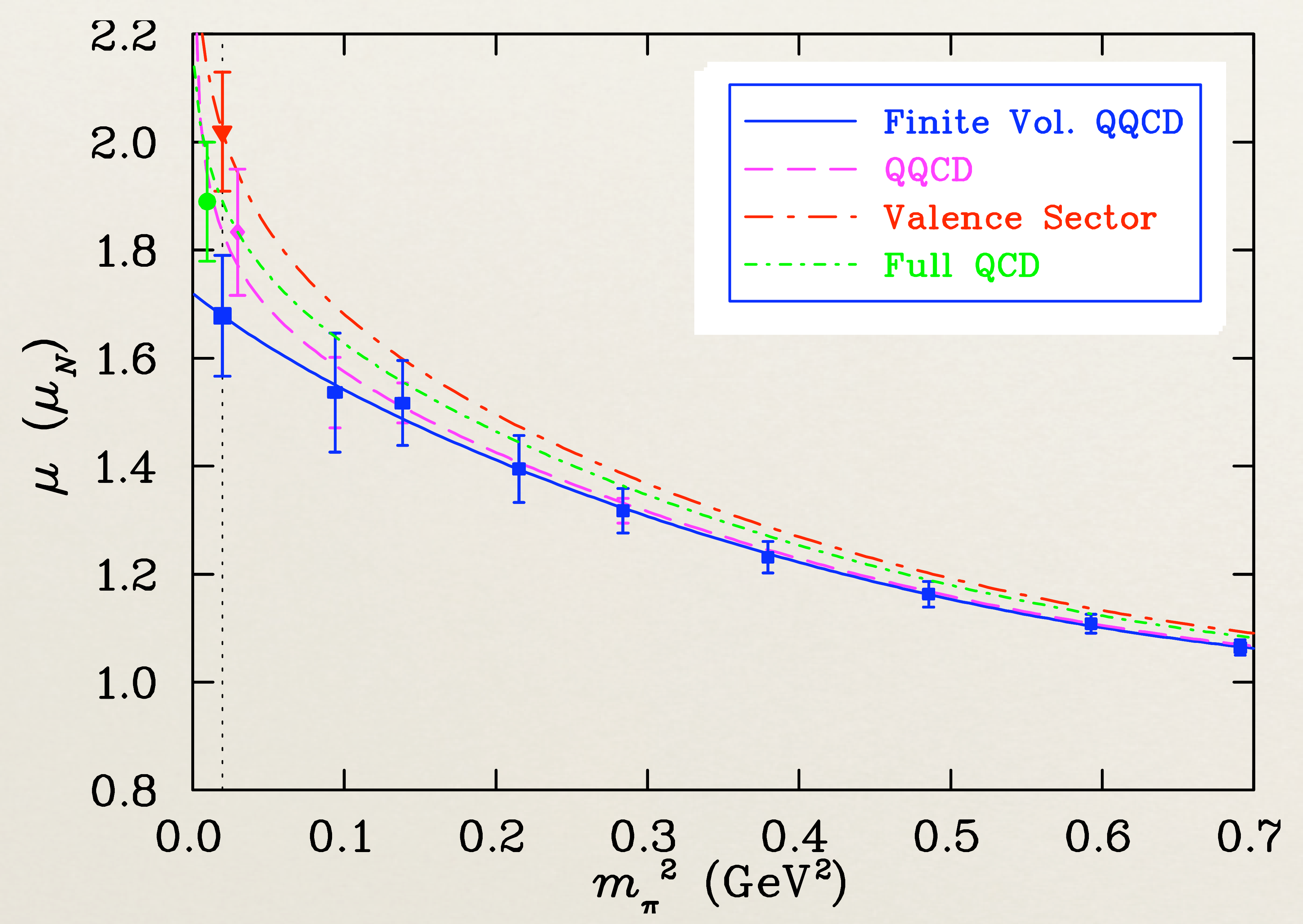
Chiral corrections



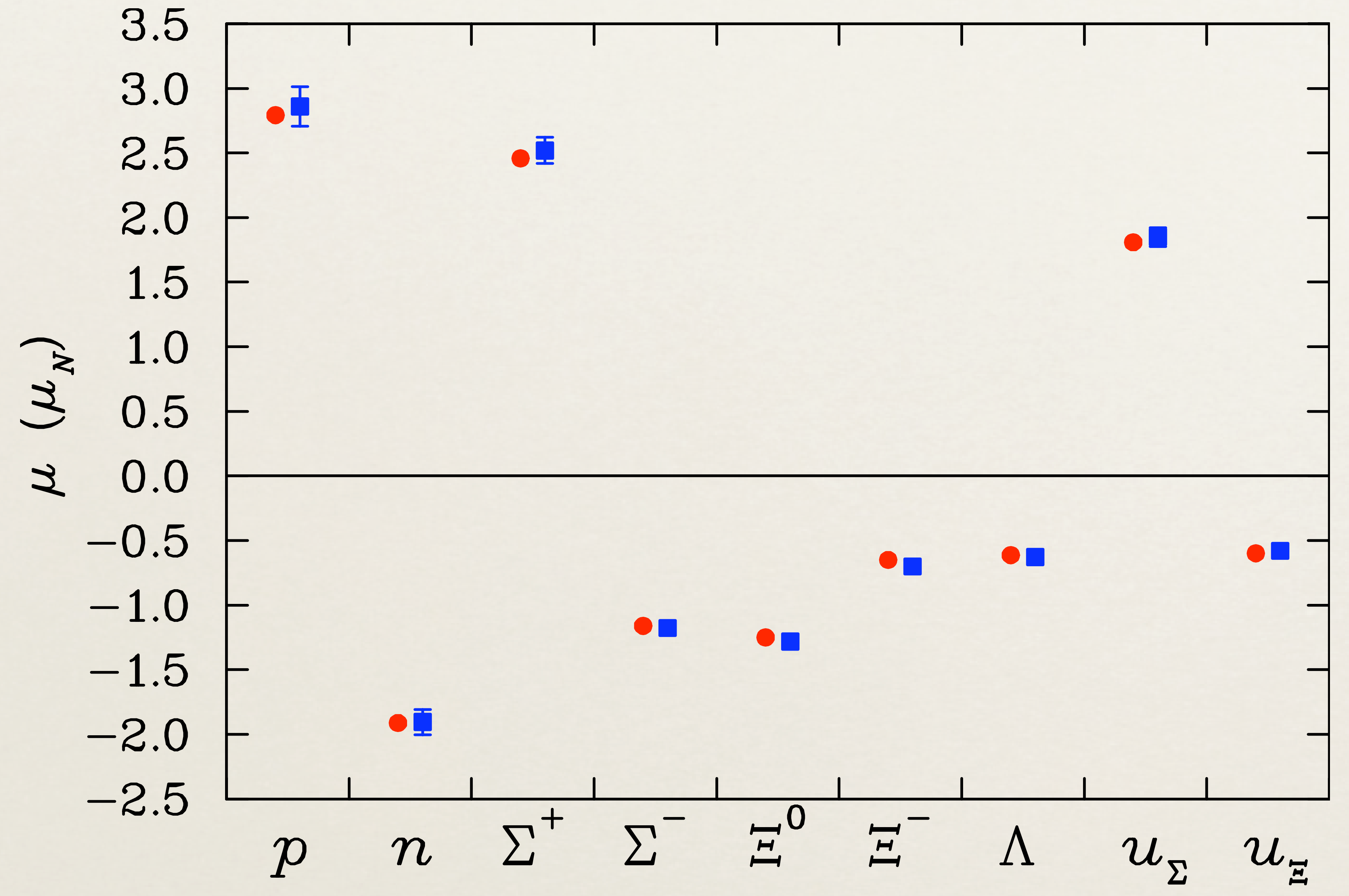
Quenched artefact

Different contributions in Quenched QCD and QCD

u-quark in the proton

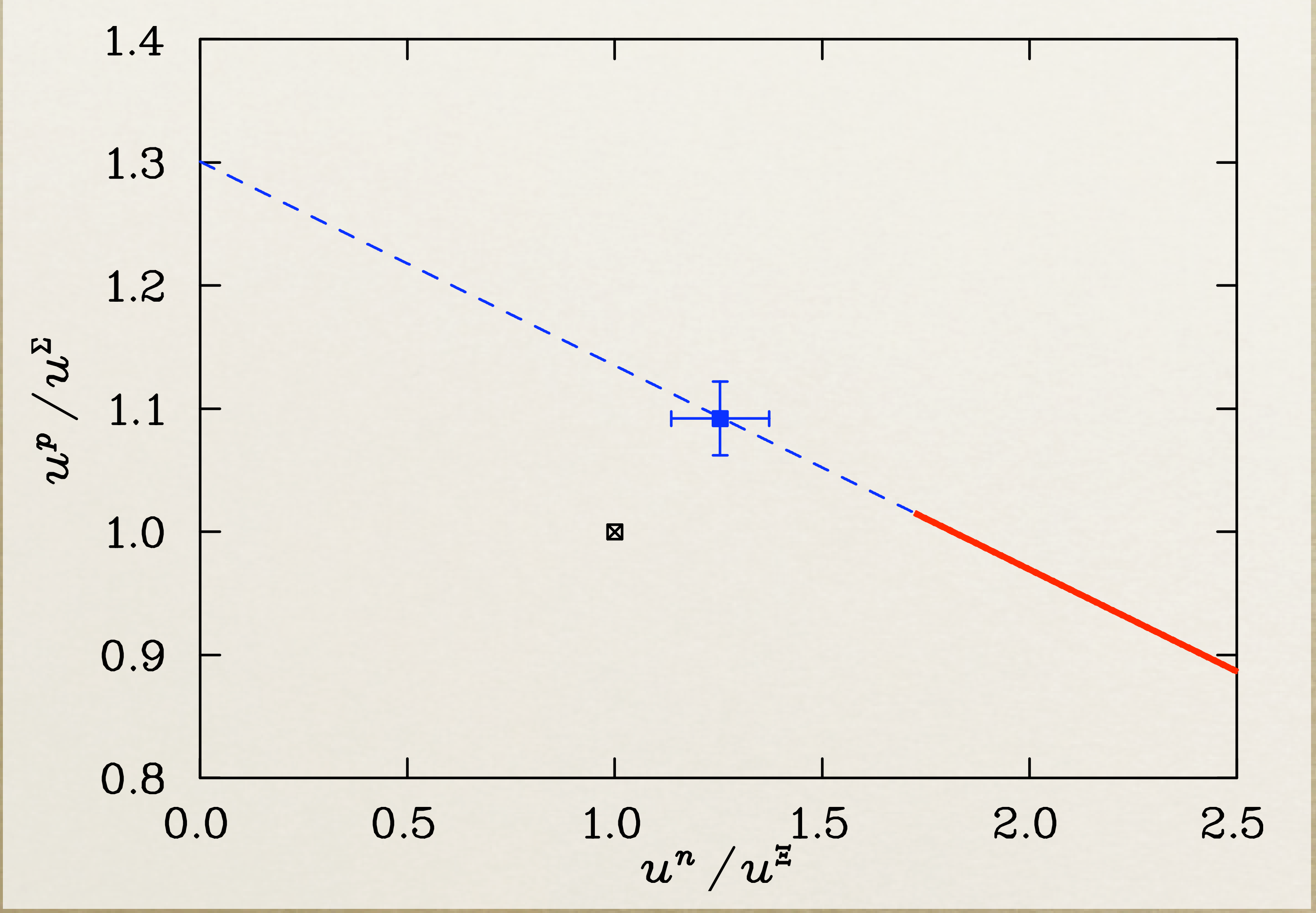


Magnetic Moments



Leinweber *et al*. PRL(2005)

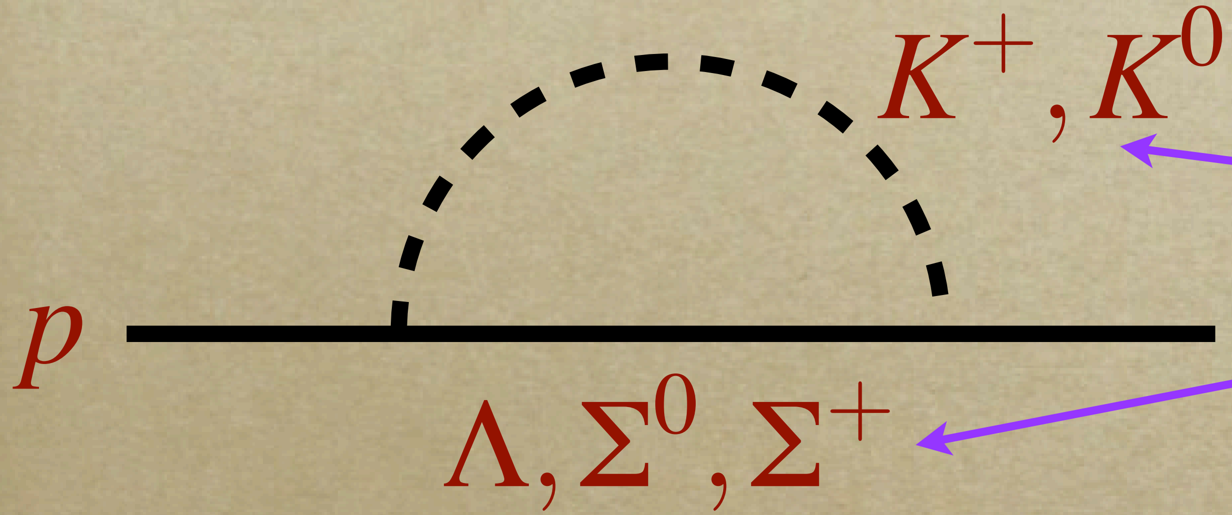
Final Result



$$G_M^s = -0.046 \pm 0.019\, \mu_N$$

Strange Signs

Lightest *strange* dof *coupling to proton*



$\bar{s}$ *in meson*

s *in baryon*

$$|\langle r^2 \rangle^E_{\bar{s}}| > |\langle r^2 \rangle^E_s| \quad \Rightarrow \quad \langle r^2 \rangle^E_s < 0$$

$$G^s_E > 0$$

Try this at home:

Slowly creep up on a proton from a long distance,

first strange thing you'll see: a K^+ *meson!*

Summary

- *Strangeness in the nucleon is interesting*
- *Nucleon mass ~-5% (maybe -30%)*
- *Momentum ~3%, Spin ~-10% (?maybe "+")*
- *Electric/Magnetic form factors*
  - *work in progress*

References

Nelson & Kaplan PLB192,193(1987)
RDY *et al.* PRD66,094507(2002)
Borasoy & Meissner Ann.Phys.254,192(1997)
Flambaum, RDY *et al.* PRD69,115006(2004)
Kaplan & Manohar NPB310,527(1988)
Beck PRD39,3248(1989)
Kumar & Souder Prog.Part.Nucl.Phys.45,S333(2000)
Zhu *et al.* PRD62,033008(2000)
SAMPLE Collaboration PLB583,79(2004)
Leinweber, RDY *et al.* PRL94,212001(2005)
Leinweber, Thomas & RDY PRL92,242002(2004)