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

\[ M_N = c_0 + c_2 m_{\pi}^2 + \chi_\pi m_{\pi}^3 + \ldots \]

ChPT:

\[ \chi_\pi \approx -0.63 \text{GeV}^{-2} \]

\[ \chi_\pi = -5.5 \text{GeV}^{-2} \]
Finite-range regularisation

\[ M_N (\text{GeV}) \]

\[ m_\pi^2 (\text{GeV}^2) \]

Leinweber, Thomas & RDY, PRL(2004)

Independent-of-model chiral extrapolation

Dipole

Theta

Monopole

Gaussian
Finite-range regularisation

Independent-of-model chiral extrapolation

Dipole
Theta
Monopole
Gaussian
Quenched QCD vs QCD

Dynamical Differences described by chiral loops

\[ m_B = a_0 + a_2 m_\pi^2 + a_4 m_\pi^4 + \sum \]

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

\[ \mu_p / (\mu_N) \]

Finite-volume
Quenched
QCD

Investigate applying technique to magnetic moment

SUCCESS
Apply techniques to strange form factors...
The Approach

Assume charge symmetry

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

\[ 3O_N = 2p + n - u^p \]

\[ 3O_N = 2p + n - \left( \frac{u^p}{u^\Sigma} \right) (\Sigma^+ - \Sigma^-) \]

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

\[ \Sigma^+ - \Sigma^- = u^\Sigma \]

\[ 3O_N = 2p + n - \left( \frac{u^n}{u^\Xi} \right) (\Xi^0 - \Xi^-) \]

\[ \Xi^0 - \Xi^- = u^\Xi \]

Lattice QCD
Constraint on GMs

\[ G_M^s > 0 \]

\[ G_M^s < 0 \]
Disconnected Loops

\[ O_N = \left( \begin{array}{c} u, d, s \end{array} \right) \]

\[ O_N = -\frac{1}{3} (l G_M^d + l G_M^s) \]

\[ = \frac{l G_M^s}{3} \left( \frac{1 - l R^s_d}{l R^s_d} \right) \]

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

\[ l G_M^u = l G_M^d \]

QCD equality for \( m_u = m_d \)

\[ l R^s_d = l G_M^s / l G_M^d = 0.139 \pm 0.042 \]

Kaon strength relative to pion
u-quark in proton

Leinweber, RDY et al. PRL(2005)
u-quark in Sigma
$\frac{u^p}{u^\Sigma} = 1.092 \pm 0.030$

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

$G_M^S = -0.046 \pm 0.022 \mu_N$
Magnetic Moments

Leinweber et al. PRL(2005)
Repeat for electric radius

Limited hyperon info, take absolute values from lattice

Valence quarks in proton

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

Leinweber, RDY et al. hep-lat/0601025
Experimental Status

- World PVES data

\[ Q^2 = 0.1 \text{GeV}^2 \]

Analysis relies upon theoretical bounds on anapole contribution, Zhu et al. PRD(2000)
G0 Experiment

\[ Q^2 (\text{GeV}^2) \]

\[ G^S_E + \eta G^S_M \]

- G0
- HAPPEX
- Arrington
- Friedrich & Walcher

\[ \Delta A_{\text{glob}} \]
\[ \Delta A_{\text{model}} \]

PRL95(2005)
Global Analysis

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

\[
\tilde{G}_A^N = \tilde{g}_A^N \left( 1 + \frac{Q^2}{\Lambda^2} \right)^{-2}
\]

\[
G_E^s = \rho_s Q^2 + \rho'_s Q^4 + \ldots
\]

\[
G_M^s = \mu_s + \mu'_s Q^2 + \ldots
\]
GMs–GEs

RDY et al. nucl-ex/0604010
HAPPEX
P. Souder APS2006

Theory, Leinweber et al.

HAPPEX - H (2005)

HAPPEX - ^4He (2005)

Global Analysis (G0, PVA4, SAMPLE, + older HAPPEX data)

68% CL

95% CL
Theoretical analysis by Leinweber et al.

\[ G_s M = +0.01 \pm 0.29 \mu_N \]

\[ G_s E = +0.002 \pm 0.021 \]

Global Analysis

(G0, PVA4, SAMPLE, + all HAPPEX data)
Disconnected Loops

\[ u, d, s \]

\[ = \frac{2}{3} G^u_M - \frac{1}{3} G^d_M - \frac{1}{3} G^s_M \]

\[ -6\% \quad +3\% \quad +0.5\% \]
Remarks

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

\[
\langle r^2 \rangle_E^p = 0.766 \pm 0.012 \text{ fm}^2 \\
\langle r^2 \rangle_E^s = 0.001 \pm 0.017 \text{ fm}^2
\]

- Advancing knowledge on how QCD works!
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HAPPEX