Lattice Gauge Theory for High Energy Physics

Fundamental Symmetries brief

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Letters of Interest

• Matrix elements of nucleons and light nuclei
  – Nuclear Matrix Elements for BSM Searches from Lattice QCD: Shanahan
  – Probing Scalar and Tensor Interactions at the TeV Scale: Gupta

• Electric Dipole Moments
  – Constraining Physics Beyond the Standard Model using Electric Dipole Moments: Bhattacharya
  – Calculations of nucleon electric dipole moments on a lattice with chiral fermions: Syritsyn

• Neutron-antineutron oscillations
  – $\Delta B = 2$: A State of the Field, and Looking Forward: Barrow

• Higgs Potential
  – Probing High Scale Physics via Standard Model Parameters: Dunsky
Matrix Elements

- Matrix Elements of S and T (and others) in nucleons and light nuclei
  - $\beta$-decay shape
  - Dark Matter
    - For direct detection
    - Through isotope-shift spectroscopy
  - $\mu 2e$ conversion
  - EDMs due to quark EDM
- Double-$\beta$ decay and other two-nucleon processes

Nuclear matrix elements currently at heavier quarks

Target 1% precision in nucleon charges with $10^{-4}$ $\beta$-decay experiments
Electric Dipole Moments

EDMs can constrain many models of BSM (e.g., Higgs)
EDMs of nucleons and CP-violating $\pi\text{NN}$ coupling from
- QCD $\theta$-term
- Weinberg 3-gluon term
- Quark chromo-EDM
- Various 4-quark operators

Currently the systematics are large:
- Chiral behavior
- $N\pi$ intermediate state
- Operator mixing and a extrapolation

Plans for gradient flow, physical mass quarks, chiral quarks
Need 25–50% accuracy in matrix elements
$\Delta B = 2$ processes

- Violation of B-L needed for baryogenesis
- Many natural models where proton decay suppressed
- Need n$\bar{n}$ lifetime and dinucleon decay rates

<table>
<thead>
<tr>
<th>Operator</th>
<th>$\mathcal{M}_I^{\text{MS}}(2 \text{ GeV})$, $10^{-5}$ GeV$^6$</th>
<th>$\mathcal{M}_I^{\text{MS}}(700 \text{ TeV})$, $10^{-5}$ GeV$^6$</th>
<th>$\mathcal{M}_I^{\text{MS}}(2 \text{ GeV})$ (MIT bag A)</th>
<th>$\mathcal{M}_I^{\text{MS}}(2 \text{ GeV})$ (MIT bag B)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$Q_1$</td>
<td>$-46(13) \times 10^{-5}$ GeV$^6$</td>
<td>$-26(7) \times 10^{-5}$ GeV$^6$</td>
<td>4.2</td>
<td>5.2</td>
</tr>
<tr>
<td>$Q_2$</td>
<td>$95(17) \times 10^{-5}$ GeV$^6$</td>
<td>$144(26) \times 10^{-5}$ GeV$^6$</td>
<td>7.5</td>
<td>8.7</td>
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<tr>
<td>$Q_3$</td>
<td>$-50(12) \times 10^{-5}$ GeV$^6$</td>
<td>$-47(11) \times 10^{-5}$ GeV$^6$</td>
<td>5.1</td>
<td>6.1</td>
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<tr>
<td>$Q_5$</td>
<td>$-1.06(48) \times 10^{-5}$ GeV$^6$</td>
<td>$-0.23(10) \times 10^{-5}$ GeV$^6$</td>
<td>-0.84</td>
<td>1.6</td>
</tr>
</tbody>
</table>

Rinaldi et al.
Vanishing Higgs Quartic Coupling

- Need precise determination of $\alpha_s$, $m_h$ and $m_t$
- Lattice can help with $\alpha_s$ (need about $10^{-4}$)