Introduction

Electroweak (EW) precision measurements at LEP, flavor mixing experiments at B-factories, and the discovery of the Higgs Boson at LHC put tight constraints on possible new physics beyond the Standard Model. But, hadronic EW neutral current processes by the hadronic QCD background,
intrinsic strengths of weak interactions, responsible for parity violation (PV) in hadronic processes is constrained in the Standard Model,
and can also exploit certain few-body and nuclear systems to test PV. Furthermore, current analyses show enhanced isoscalar PV, suppressed isovector PV;
neutrons central contribution to the latter,
superficially similar to the octet enhancement (\(\Delta l = 1/2\) rule) that governs strangeness changing decays,
could strong interaction explain both effects? ⇒ Lattice QCD

Model Parameters

- Most common model used for nuclear PV is meson-exchange model by Desplanques, Donoghue and Holstein (DDH)
- PV interactions encoded in seven PV couplings

\[
H_{\text{PV}} = i \left( \frac{p^2}{m} \right) N \left( \hat{f} \cdot \hat{p} \right) + \frac{m^2}{2} \left( 3 \hat{p} \hat{p} - \hat{1} \hat{1} \right) N + \frac{m^2}{2} \left( 3 \hat{p} \hat{p} - \hat{1} \hat{1} \right) N \left( \hat{r} \cdot \hat{p} \right)
\]

- Use Lattice QCD to compute \(pp\) PV matrix element directly ⇒ improve constraints on isoscalar combination \((h_0^2 = 0.7\Delta C_0)\)

Lattice QCD Approach

- PV interactions described by short-range effective operators \(\Delta l = 0, 1, 2\)
- Calculations of nuclear matrix elements for \(\Delta l = 0, 1\) involve expensive computations of quark-line disconnected diagrams ⇒ we first study \(n = 2\)

\[
C_{\text{PV}}(t, t_i, t_f) = \langle pp | \mathcal{T} \left( \bar{p} p \delta(t - t_f) \right) | pp \rangle
\]

- 5-point correlation function

\[
C_{\text{PV}}(t, t_i, t_f) \rightarrow \left( pp \right) (P_0, t_f) \text{ and } \left( pp \right) (P_0, t_i)
\]

good: no operator mixing and only connected contributions in isospin limit

- Challenges:

  - process features 2208 diagrams ⇒ automatic code generation (see other poster)
  - interpolating operator for higher partial wave \(P_3\) has to be constructed
  - many-point functions involving Baryons are extremely noisy ⇒ code optimization for being able to gather huge amount of statistics
  - non-trivial finite volume dependence
  - exponential degradation of signal-to-noise ratio with decreasing pion mass
  - \(C_{\text{PV}}\) needs renormalization

Normalization

- Lattice interpolating operators have overlap with a tower of states ⇒ euclidian correlation functions can be written as sums over exponentials, decaying with masses \(m_\pi\)

\[
C(t_i, t_f) = \langle \bar{p}(t_i) | \bar{p}(t_f) \rangle \sim \sum_{n=1}^{\infty} Z_n e^{-m_\pi(t - t_f)}
\]

Factors \(Z_n\) represent the overlaps of the proton creation and annihilation operators \(\bar{p}, p\) with corresponding state \(\langle n \rangle\) at source or sink

cancel vacuum overlaps by computing the ratio:

\[
R(t_i, t_f) = \frac{C_p(t_i, t_f)}{\sqrt{C_{\text{PS}}(t_i, t_f) C_S(t_i, t_f)}}
\]

Where \(C_p, C_S\) are P- and S-wave di-proton correlation functions

Preliminary Results

- excited energy plots for \(C_p, C_S\) suggest region with insignificant excited state contaminations

Figure: Experimental constraints on linear combinations of isoscalar and isovector DDH model.

- plateau is linear in \(t\) ⇒ possible \(O(e^{-\frac{\Delta l}{2}E(t)}}\) contaminations

Figure: Ratio \(R(t_i, t_f)\) shows linear dependence in \(t\) due to nearby energy levels.

Renormalization

- For targeted precision: NLO perturbative renormalization sufficient
- Relevant diagrams on quark level are \(W\) and \(Z\)-exchange diagrams
- Wilson coefficient of \(\Delta l = 2\):

\[
C_{\text{PV}}(t_i, t_f) = \frac{1}{\sqrt{C_{\text{PS}}(t_i, t_f) C_S(t_i, t_f)}} \left( C_{\text{PV}} - \frac{\alpha_s(t_f)}{4\pi} \right)
\]

with known tree-level coefficients \(C_{\text{PV}}^{(0)}\), \(C_{\text{PS}}^{(0)}\), \(C_S^{(0)}\)

Conclusion

- Nuclear PV can be computed on the lattice for large \(m_\pi\)
- Energy levels not well separated ⇒ generalized eigenvalue techniques or summation method
- \(\Delta l = 0, 1\) involve disconnected diagrams ⇒ multigrid solver
- Map out pion mass dependence

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