Taming quark chromoEDM contribution to the neutron EDM

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Introduction
Form Factors

Vector form-factors
Dirac F_1, Pauli F_2, Electric dipole F_3, and Anapole F_A

Sachs electric $G_E \equiv F_1 - (q^2/4M^2)F_2$ and magnetic $G_M \equiv F_1 + F_2$

$$\langle N|V_\mu(q)|N\rangle = \overline{u}_N \left[\gamma_\mu F_1(q^2) + i\frac{[\gamma_\mu,\gamma_\nu]}{2} q_\nu \frac{F_2(q^2)}{2m_N} + (2i\, m_N \gamma_5 q_\mu - \gamma_\mu\gamma_5 q^2) \frac{F_A(q^2)}{m_N^2} + \frac{[\gamma_\mu,\gamma_\nu]}{2} q_\nu\gamma_5 \frac{F_3(q^2)}{2m_N} \right] u_N$$

- The charge $G_E(0) = F_1(0) = 0$.
- $G_M(0)/2M_N = F_2(0)/2M_N$ is the (anomalous) magnetic dipole moment.
- $F_3(0)/2m_N$ is the electric dipole moment.
- F_A violates PT; F_3 violates CP.

Introduction
Phase convention

- Theory does not have P symmetry,
- but asymptotic In and Out states do.
- Not necessarily implemented by γ_0.

In fact,

$$\Sigma \cdot F \propto \begin{pmatrix} \sigma \cdot B & i\sigma \cdot E \\ i\sigma \cdot E & \sigma \cdot B \end{pmatrix},$$

which is $\sigma \cdot B$ in the rest frame only if $(i\not{p} + m) = 0$.
Previous calculations had missed this effect: including it reduces the signal.

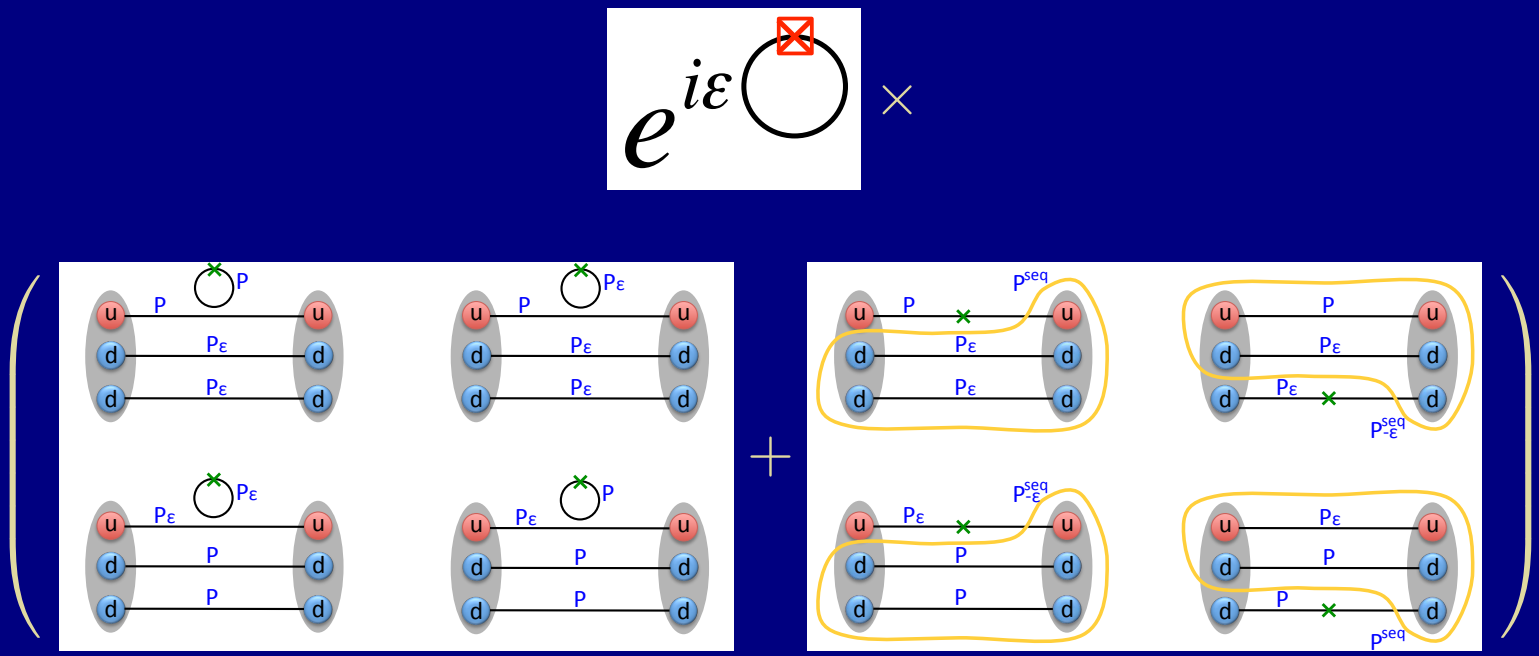
Introduction
BSM Operators

Standard model CP violation in the weak sector.
Strong CP violation from dimension 3 and 4 operators anomalously small.

- Dimension 3 and 4:
  - CP violating mass $\bar{\psi}\gamma_5\psi$.
  - Toplogical charge $G_{\mu\nu}\tilde{G}^{\mu\nu}$.
- Suppressed by $v_{\rm EW}/M^2_{\rm BSM}$:
  - Electric Dipole Moment $\bar{\psi}\Sigma_{\mu\nu}\tilde{F}^{\mu\nu}\psi$.
  - Chromo Dipole Moment $\bar{\psi}\Sigma_{\mu\nu}\tilde{G}^{\mu\nu}\psi$.
- Suppressed by $1/M^2_{\rm BSM}$:
  - Weinberg operator (Gluon chromo-electric moment): $G_{\mu\nu}G_{\lambda\nu}\tilde{G}_{\mu\lambda}$.
  - Various four-fermi operators.

Lattice Calculation

Three-point function

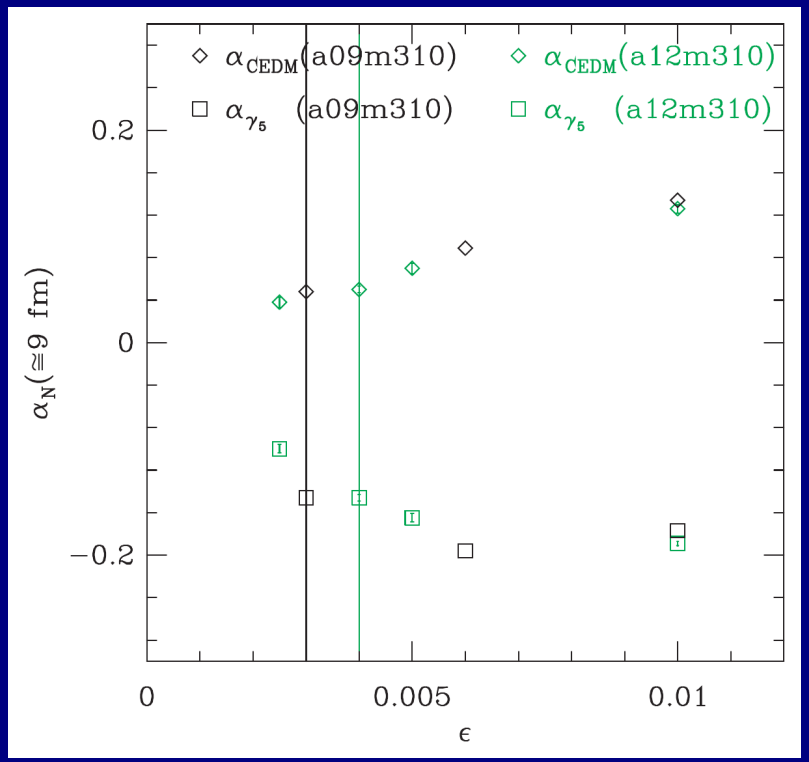


The chromoEDM operator is dimension 5.
Uncontrolled divergences unless $\epsilon \lesssim 4\pi a \Lambda_{\rm QCD} \sim 1$.
Need to check linearity.

Lattice Calculation

Two-point function

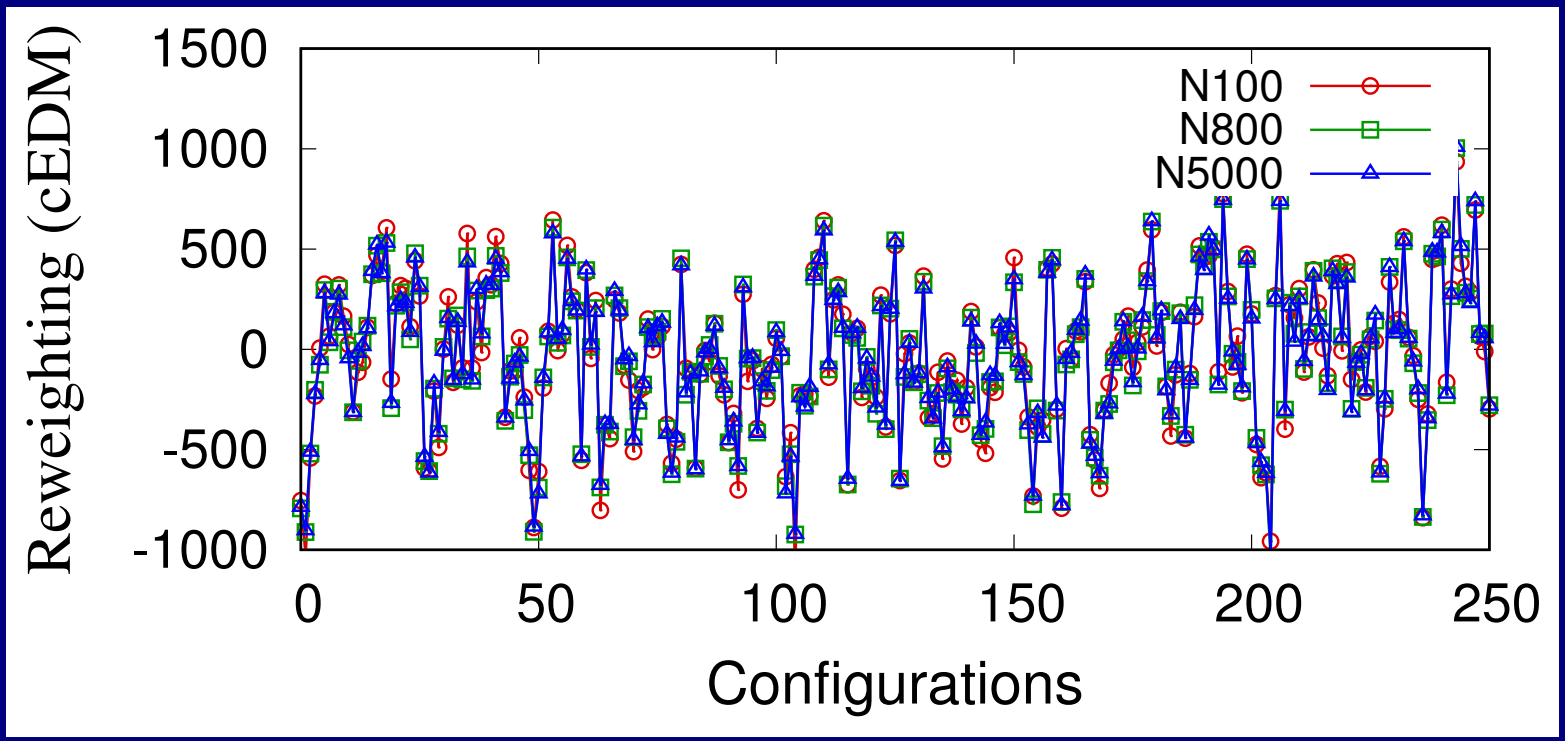
Find asymptotic Parity operator: $e^{i\alpha\gamma_5}\gamma_0$ from two-point function.



Preliminary; Connected Diagrams Only

Lattice Calculation

Disconnected diagrams



Also calculate disconnected contribution to flavor diagonal (isoscalar) charges.

SPC questions

Agreement between groups

Ensembles	PNDME	CalLAT	χQCD
a12m310	1.229(14)	1.237(07)	1.22(4)
a12m220S	1.270(40)	1.272(28)	
a12m220	1.240(32)	1.259(15)	
a12m220L	1.255(16)	1.252(21)	
a09m310	1.231(33)	1.258(14)	1.21(3)

SPC questions
Spatial versus Temporal

$$\bar{\psi}\gamma_5\sigma_{\mu\nu}\overleftrightarrow{D}_\nu\psi \propto \bar{\psi}\gamma_5\gamma_\mu(\not{D}-m)\psi + m\bar{\psi}\gamma_5\gamma_\mu\psi$$

- The first contributes $O(a^2)$ except for contact terms.
- The second is a mass dependent renormalization.
- We use space component and assign 2–3% for $O(a^2)$.
- Our estimates agree.

Conclusions
Request

- Analyze $32^3 \times 96$ a09m310
- Disconnected diagrams
- cEDM and Quark bilinears
  - Axial form factors
  - Vector form factors
  - Flavor diagonal scalar and tensor charges

43M Jpsi core hours.