

My input is based on calculations of
nucleon charges, form-factors,
TMDs, and ME of novel CP
violating (nEDM) operators in the
neutron state

Many thanks to my collaborators and colleagues

Clover on 2+1+1 flavor HISQ lattices: ~1000 configs

- m_s set to its physical value using $M_{\pi SS}$

a(fm)	m_l/m_s	Lattice Volume	$M_{\pi} L$	M_{π} (MeV)	Configs. X sources
0.12	0.2	$24^3 \times 64$	4.54	305	1013 x 8
0.12	0.1	$24^3 \times 64$	3.22	217	1000 x 12
0.12	0.1	$32^3 \times 64$	4.3	217	958 x 8
0.12	0.1	$40^3 \times 64$	5.36	217	1010 x 8
0.09	0.2	$32^3 \times 96$	4.5	313	881 x 8
0.09	0.1	$48^3 \times 96$	4.71	220	890 x 8
0.09	0.035	$64^3 \times 96$	3.66	130	883 x 4
0.06	0.2	$48^3 \times 144$	4.51	320	865 x 4
0.06	0.1	$64^3 \times 144$	4.25	229	200 x 4

Need at least 3 values of a and m_q

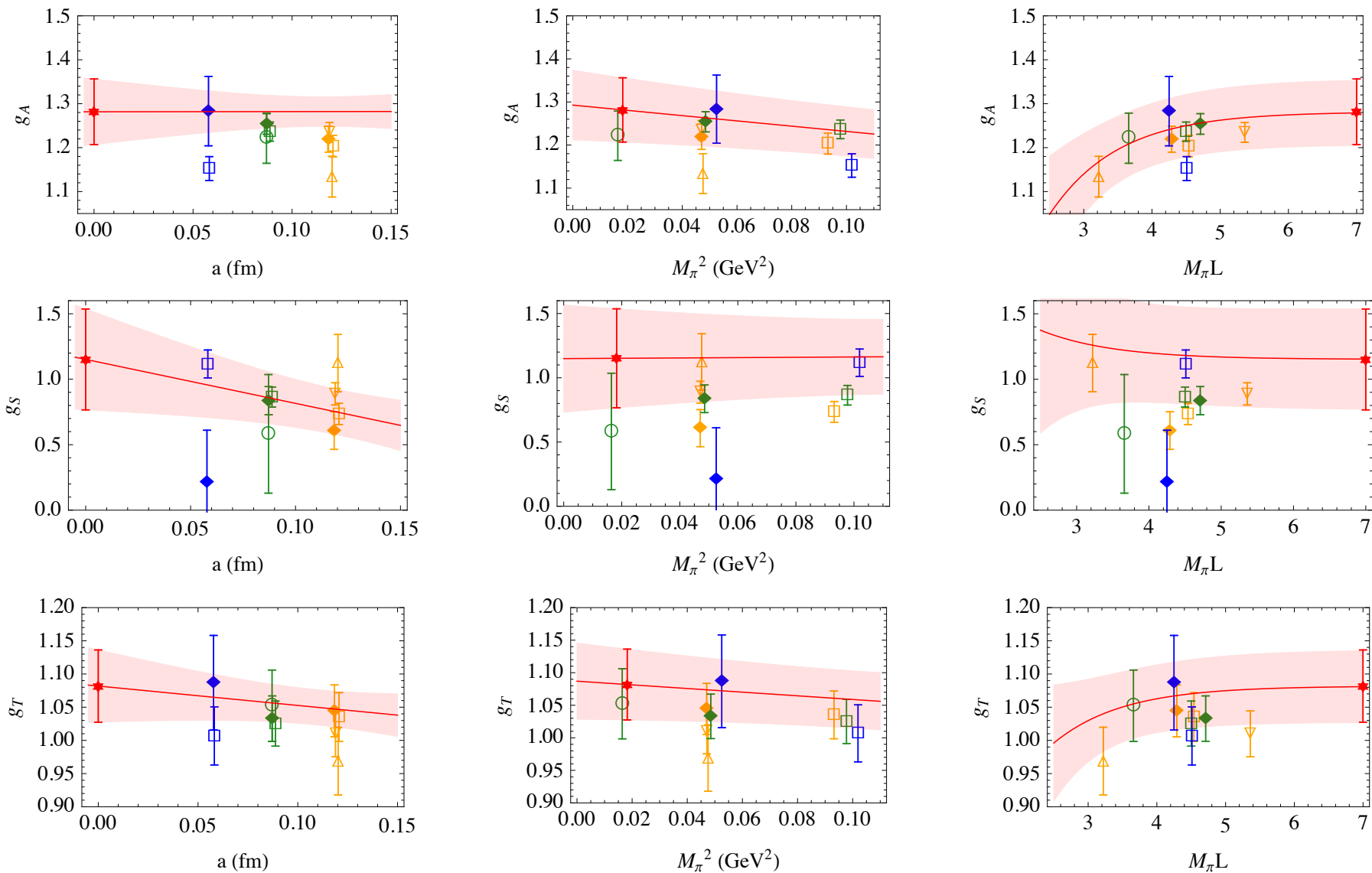
Study of extrapolations in a , M_π^2 , L (*Ansatz for charges g_A , g_S , g_T*)

$$g(a, M_\pi, L) = g + A a + B M_\pi^2 + C e^{-M_\pi L} + \dots$$

We use the lowest order corrections when fitting 9 points

- Lattice spacing a
- Dependence on quark mass $m_q \sim M_\pi^2$
- Finite volume

★: Need to resolve all three systematics



Orange: $a=0.12$; Green: $a=0.09$; Blue: $a=0.06$ fm

□=310; ◆=220; ○=130 MeV

Observations and Lessons Learned

- Exceptional configurations: Clover-on-HISQ with HYP smearing:
 - Exist on the $a=0.12\text{fm}$ lattices with $M_\pi=130\text{MeV}$ [do clover or DWF scale?]
 - None found for $a=0.09$ and 0.06 lattices
- Statistics: $\sigma(g_S) \sim 5 \sigma(g_A)$ [or $5 \sigma(g_T)$]
Need $O(15000)$ independent measurement (Configs \times Sources)
- Excited state contamination is significant. Need:
 - multiple T_{sep} with good signal for $T_{\text{sep}} > 1.2\text{fm}$
 - fits including at least one excited state to $T_{\text{sep}} > 1.0\text{fm}$ data
- Renormalization (RI-sMOM): Smearing introduces artifacts.
Need a prescription with a well-defined continuum limit

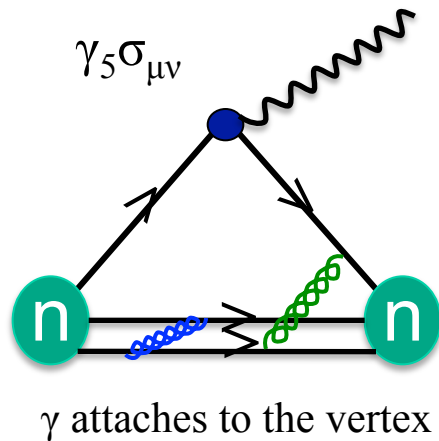
Summary: Computing & People Needs

- Needs for 1% estimates based on current “improved” techniques
 - 2+1+1 flavor ensembles
 - At least 3 values of a ($a=0.09, 0.06, 0.045$)
 - Three values of m_q ($M_\pi = 250, 200, 140$ MeV)
 - O(2000) configurations [analyzed with 12-24 source points on each]
 - Spatial size: $M_\pi L > 5$
 - Analysis: 500 million node hours
- Support for post-docs and staff is crucial
 - 3-4 staff and 3-4 post-docs

CP Violation, Baryogenesis, nEDM

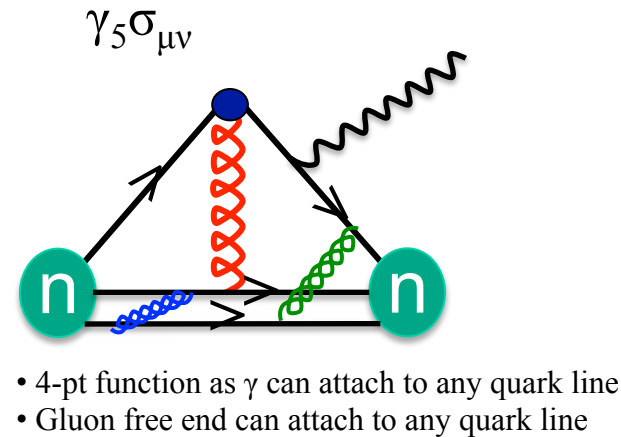
ME of novel CP violating operators: nEDM

Quark-EDM



$$\bar{q} \sigma_{\mu\nu} \gamma_5 q F^{\mu\nu}$$

Chromo-EDM



$$\bar{q} \sigma_{\mu\nu} \gamma_5 q \lambda^a G_a^{\mu\nu}$$

- Formulation of the problem
- Operator mixing and renormalization
- Signal in disconnected diagrams
- Formulating lattice calculation of chromo EDM, a 4-point function