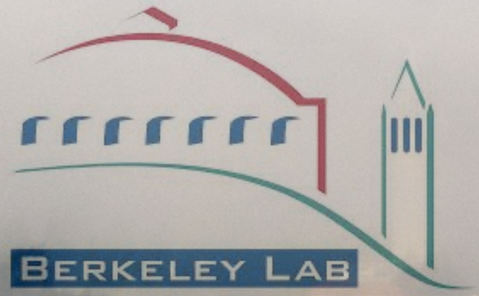
Nuclear Theory for New Physics

Collaboration Meeting: June 1-2, INT

André Walker-Loud



Website

We have a website! https://a51.lbl.gov/~ntnp/TC/

Currently hosted on my desktop — we could also host it via github sites

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Method	Pros	Cons
current location	- more control of design - intake form(s) for papers	- can be unstable eg. down this weekend - can be slow to load
github pages	- stable - easy for others to contribute - markdown pages	- limited control of page layout - no ability (that I know of) to make forms for listing papers

Who are we?

Faculty/Staff

Amy Nicholson
UNC Chapel Hill

Colin Morningstar
Carnegie Mellon University

Andrea Shindler
Aachen University
& UC Berkeley

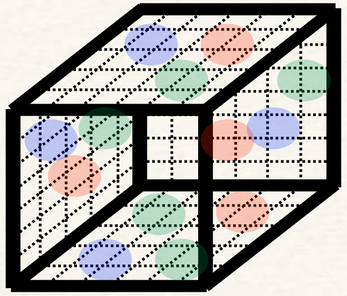
André Walker-Loud
LBNL/UC Berkeley

Postdocs

Grad Students

Zack Hall
UNC Chapel Hill
DOE SCGSR @ LBNL

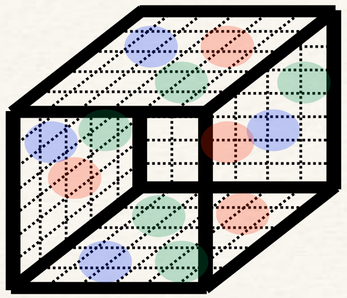
What are our foci?



Lattice QCD

- QED corrections to neutron β-decay
  - LQCD+QED corrections to g_A
  - → neutron decay amplitude
- ν-N cross section
  - LQCD/pheno discrepancy
  - N-to-Δ inelastic with novel method
  - NN corrections (?)
- Nucleon EDM
  - from QCD θ-term
  - from BSM sources

- BETA-1
  - Y1: QED corrections to g_A
  - Y2: LQCD+QED methods for $n \to pe\bar{\nu}$
  - … R&D
  - Y5: $n \to pe\bar{\nu}$ amplitude
- XSEC-1
  - Y1: elastic $\nu - N$ cross section
- XSEC-2
  - Y2-3: $N \to \Delta, N\pi$
  - Y3: $N \to N\pi\pi$
- XSEC-X
  - Y3+: g_A^{NN}?
- EDM-X
  - gutted from proposal in reduced scope: anything we do will be a bonus!



BETA-1: LQCD+QED for $n \to pe\bar{\nu}$

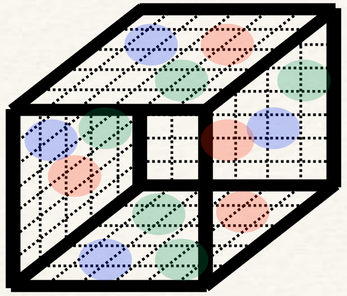
Lattice QCD

- Goal: compute neutron decay amplitude with LQCD+QED
- Motivation: recent work uncovered 2% shift in g_A due to QED — previously missed in literature
  Cirigliano et al., PRL 129 (2022) [2202.10439]
  comparing LQCD g_A to experiment is now limited by this uncertainty
  While dispersive methods are very powerful — we need to control radiative QED corrections at 10^{-4} level of precision — could they be missing a correction at this precision?

- Method: use LQCD + QED to compute the neutron decay amplitude
  this introduces several challenges
  - renormalization
  - treatment of electron and photon
  seems like a tractable problem on the ~5-year time scale

- Synergy: Need to understand finite volume (FV) and finite m_γ dependence of amplitude, renormalization
  such corrections can be understood with EFT
- Warm up: probably, warm up with simpler problem such as $K \to \pi\ell\nu$

XSEC-1 & 2: LQCD for $\nu - N$



Lattice QCD

- Goal: compute elastic and resonant inelastic nucleon structure
  integrate these results into MC event generators

- Motivation: LQCD does (will) provide critical input for $\nu - N$ reactions that are poorly constrained
  the LQCD results impact the precision goals and interpretation of $\nu - A$

- Method: use LQCD to compute the nucleon elastic form factors with momentum space source (sLapH)
  use same method to compute the $N \to \Delta, N\pi$ transition amplitudes

- Synergy: These results will also inform us of the LECs needed for Δ-full baryon χPT
  couple LQCD results to many-body methods
  we will be able to test the convergence pattern/radius of baryon χPT

- Challenge!: See if we can compute 2-nucleon electroweak matrix elements

Backup

QED corrections to neutron β-decay

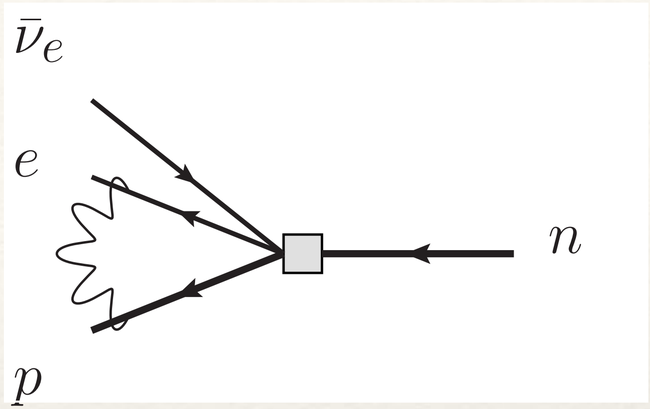
- Recent work uncovered an O(2%) QED correction to g_A, (previously estimated at 0.2%)
  Cirigliano, de Vries, Hayen, Mereghetti, Walker-Loud, PRL 129 (2022)

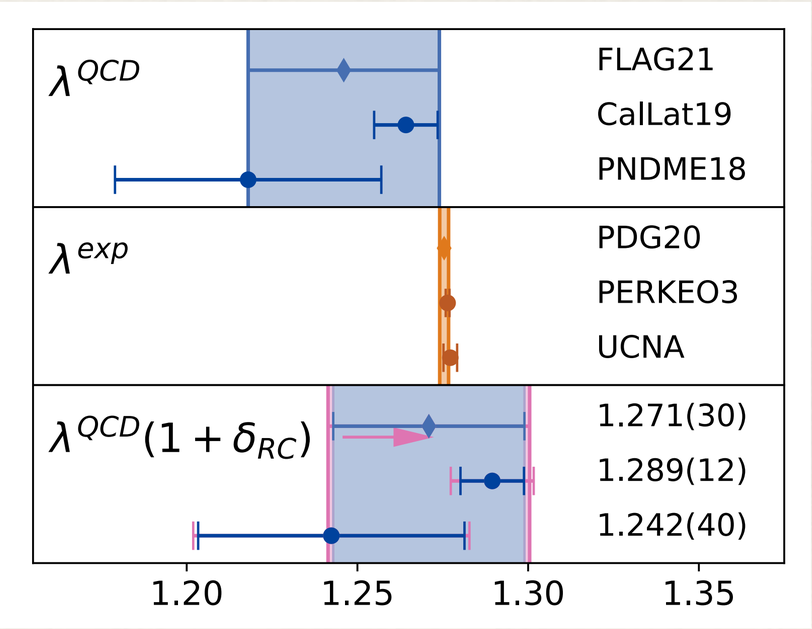
- Limiting factor comparing experiment and LQCD to constrain BSM right-handed currents

- LQCD + QED can be used to determine this correction

- Given that this term was missed with other theory methods, and QED corrections need to be controlled at 10^{-4} level, could there be other hadronic corrections important for gV and therefore a determination of V_{ud}?

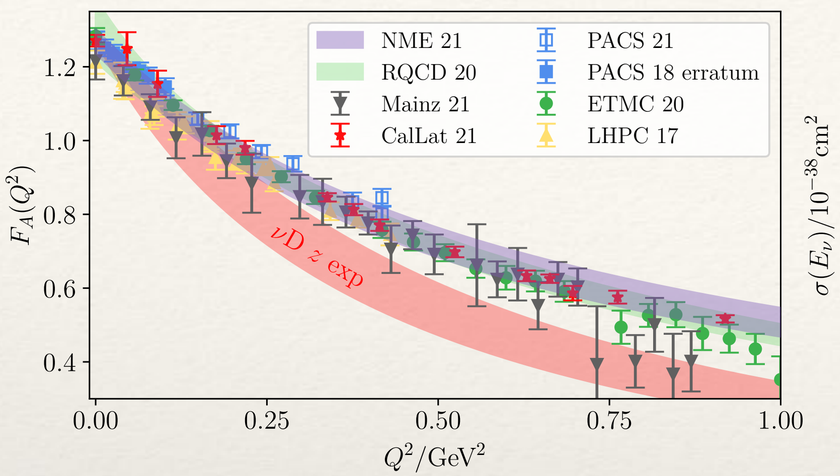
- We need a fully non-perturbative LQCD+QED calculation of neutron β-decay to validate the more recent dispersive determinations (or uncover larger corrections)

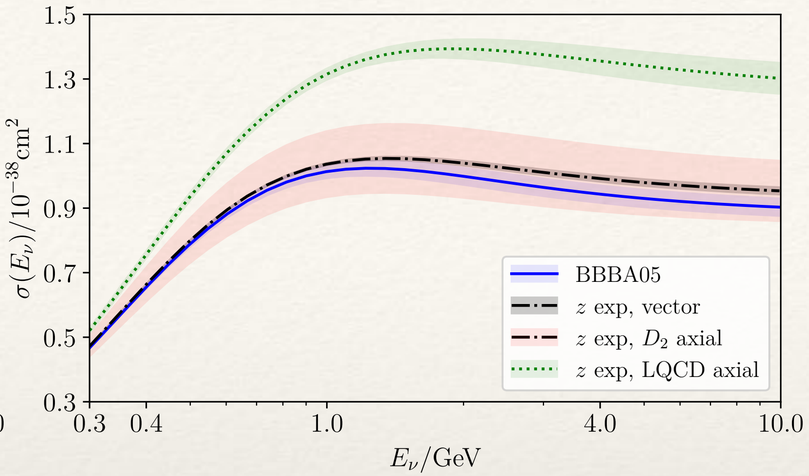




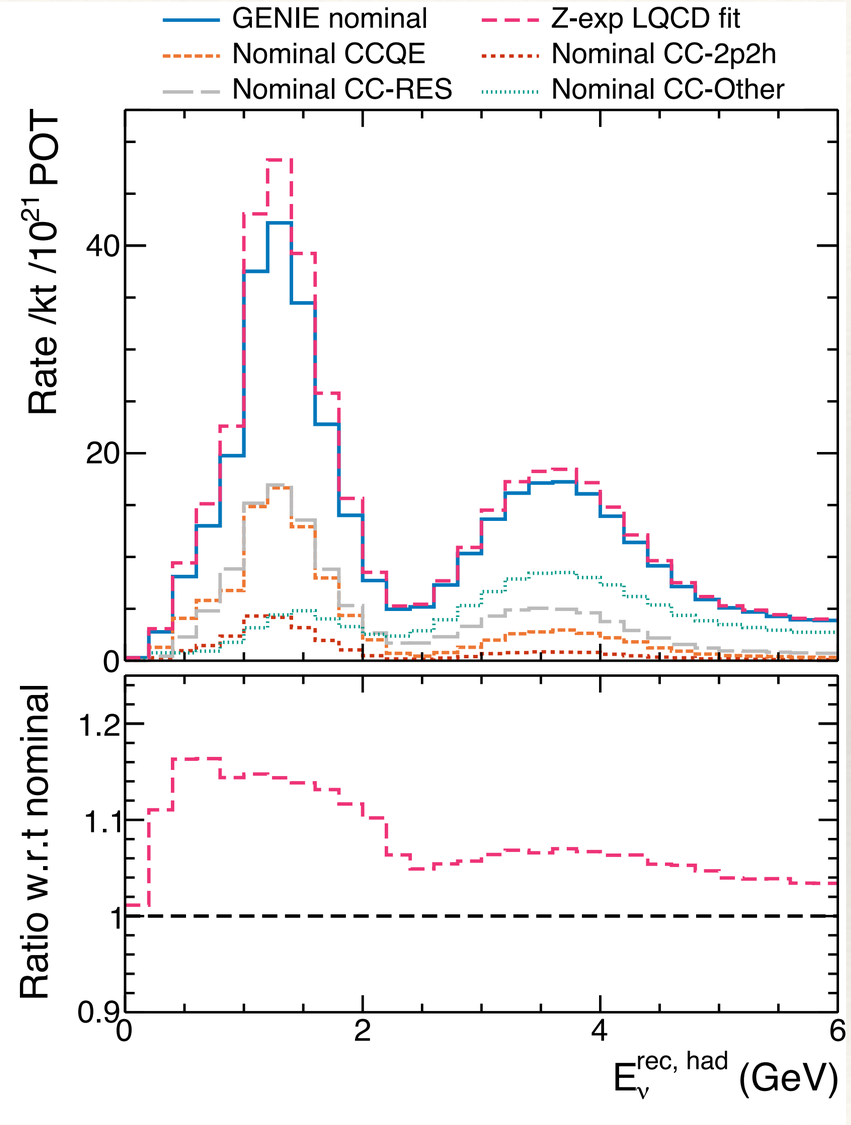
ν-N cross section

Meyer, Walker-Loud, Wilkinson
Ann. Rev. Nucl. Part. Sci. 72 (2022)



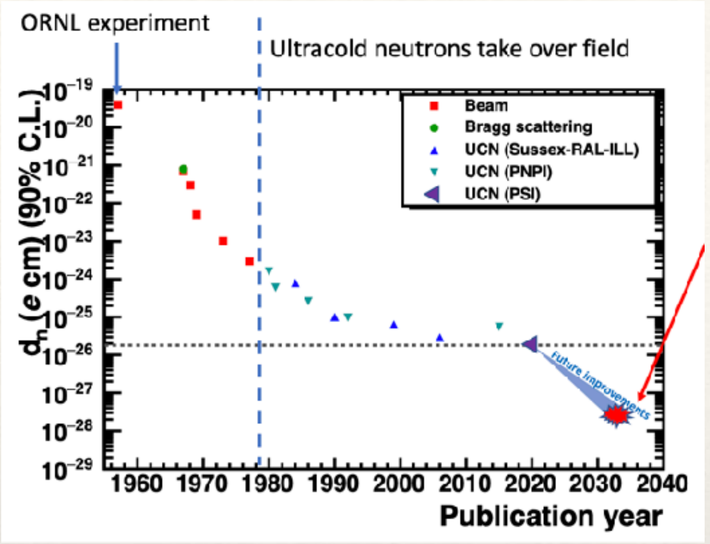


- Lattice QCD determination of $F_A(Q^2)$ is inconsistent with older phenomenological extraction
- results in 30% increase in ν-N cross section
- Energy dependent change in DUNE near/far detector
- Use novel method (stochastic Laplacian Heaviside) to
  - solidify LQCD determination
  - Explore inelastic N-to-Δ transitions - next most important contribution to ν-A



neutron EDM

Shindler:
Eur.Phys.J.A 57 (2021) 4, 128

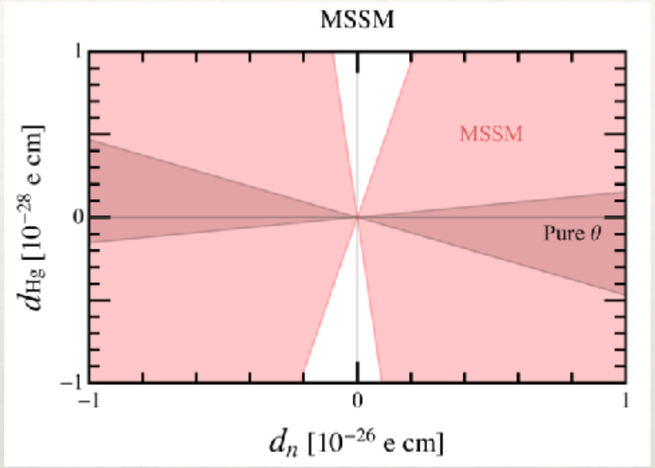


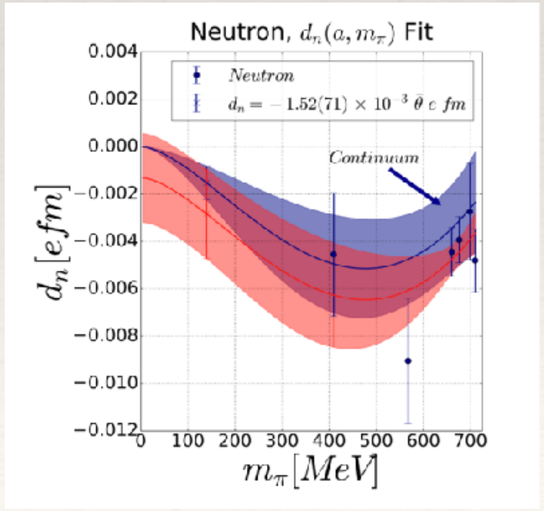
$|d_n| < 1.8 \times 10^{-26}\ e\ \text{cm}\ (90\%\ \text{C.L.})$

Abel et al.:
Phys.Rev.Lett. 124 (2020) 8, 081803

$$(d_n)_{\text{SM}=(1-6)\times 10^{-32} e\ \ \text{cm}}$$

$$d_n = -(1.5 \pm 0.7) \cdot 10^{-3} \bar{\theta} e\ \text{fm} - (0.2 \pm 0.01) d_u + (0.78 \pm 0.03) d_d + (0.0027 \pm 0.016) d_s - (0.55 \pm 0.28) e \tilde{d}_u - (1.1 \pm 0.55) e \tilde{d}_d + (50 \pm 40)\text{MeV} e \tilde{d}_G$$





Dragos, Luu, Shindler, de Vries, Yousif:
Phys.Rev.C 103 (2021) 1

- 6 orders of magnitudes of background-free window for BSM discovery
- Lattice QCD provides the only theoretically robust way to determine hadronic matrix elements -> only way to interpret experimental results and disentangle all CP violating sources
- Need a portfolio of EDM experiments. Single EDM experiment not sufficient even if the LEC are correlated in a given model
- Use new method based on the GF to overcome the major hurdle (renormalization) that has prevented in the past any lattice EDM calculation -> first results on the θ term
- Goal —> Calculate all relevant contributions to the neutron EDM from the theta term and from BSM physics