USQCD SPC report: Precision Electroweak and QCD

James Simone

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Eight proposals related to precision EW & QCD

1. *$K \to \pi\pi$ decay at the phys. point with periodic BCs*, Tomii – RBC & UKQCD
2. *Muon g-2 HVP from N_f=2+1+1 HISQ*, Lynch – Fermi-MILC
3. *Continuation: QCD + QED studies*, Jin – Uconn & BNL
4. *Semileptonic B decays with a vector final state*, Lytle – Fermilab-MILC
5. *New ensembles for precision light-meson decay constants*, Gottlieb – MILC
6. *Scale setting studies on the MILC HISQ ensembles*, Bazavov – Fermi-MILC
7. *From BSM to α_s in QCD at the Z-pole: 2023-2024*, Kuti – LatHC
8. *Gradient flow renormalization scheme*, Hasenfratz & Witzel

Motivation

Precision Weak decays

$\lvert V_{ud} \rvert$ $\pi \to \ell\nu$	$\lvert V_{us} \rvert$ $K \to \ell\nu$ $K \to \pi\ell\nu$	$\lvert V_{ub} \rvert$ $\bar{B} \to \pi\ell\nu$
$\lvert V_{cd} \rvert$ $D \to \ell\nu$ $D \to \pi\ell\nu$	$\lvert V_{cs} \rvert$ $D_s \to \ell\nu$ $D \to K\ell\nu$	$\lvert V_{cb} \rvert$ $\bar{B} \to D^* \ell\nu$
$\lvert V_{td} \rvert$ B^0_d-$\bar{B}^0_d$	$\lvert V_{ts} \rvert$ B^0_s-$\bar{B}^0_s$	$\lvert V_{tb} \rvert$ ~ 1

$K \to \pi\pi$ and CP-violation ϵ' $\Rightarrow$ talk

Heavy meson decays and experiments at BES III, Belle II, and LHCb.

SM predictions for $|V_{cb}|$ and $R_{\tau/\ell}(D^*_{(s)})$.

QED effects needed for precision $|V_{ud}|$, $|V_{us}|$.

Muon g-2

The hadronic contibutions to muon g-2 contribute the leading uncertainty to the SM calculation.

The lattice calculation is a priority for both USQCD and the world-wide community.

Precision $\alpha_{\overline{MS}}$

QCD coupling, $\alpha_{\overline{MS}}$, is a leading source of uncertainty in SM rates for $H \to gg$ and $H \to b\bar{b}$.

Muon g-2 HVP from HISQ: accomplishments

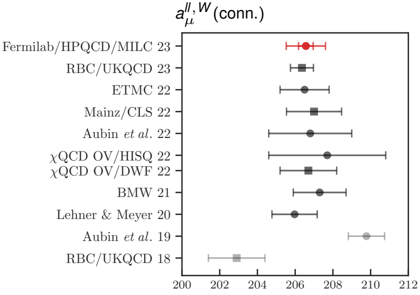


TABLE IV. Approximate error budgets for $a_\mu^{ll,\mathrm{W}}$(conn.) and $a_\mu^{ll,\mathrm{W2}}$(conn.).

Source	$\delta a_\mu^{ll,\mathrm{W}}$(conn.) (%)	$\delta a_\mu^{ll,\mathrm{W2}}$(conn.) (%)
Monte Carlo statistics	0.19	2.44
Continuum extrapolation ($a \to 0$, Δ_{TB})	0.34	1.05
Finite-volume correction (Δ_{FV})	0.16	0.23
Pion-mass adjustment (Δ_{M_π})	0.06	0.96
Scale setting (w_0 (fm), w_0/a)	0.24	1.28
Current renormalization (Z_V)	0.17	0.16
Total	0.50%	3.18%

arXiv:2212.12648

The value of $a_\mu^{ll,W}$(conn.) in the "intermediate window", $a \in [0.4, 1.0]$ fm, was proposed by RBC/UKQCD and has been adopted as a benchmark quantity to compare lattice determinations of HVP.

Intermediate-window contribution (left) is less sensitive to discretization effects from short distances and noise from long distances.

Fermilab MILC did a blind analysis and has published a complete error budget.

Muon g-2 HVP from HISQ: plans

Use USQCD and LCF resources to approach the goal of computing the leading-order HVP contribution with subpercent precision.

This project addresses significant uncertainties in the recent calculation from finite volume and electromagnetic effects.

A companion project, scale setting on HISQ ensembles, addresses the other significant uncertainty.

This year begins an exploratory calculation of QED corrections to HVP at leading order by calculating the single-photon exchange diagrams. Testing various noise reduction techniques is planned.

Project requests LQ2 GPU cluster time since the large GPU and system memories will help when computing the needed eigenvectors.

QCD + QED studies – Tomii – RBC & UKQCD

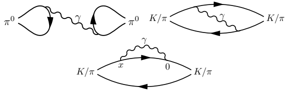


Figure 1: Diagrams for QED corrections to pion and kaon masses, son

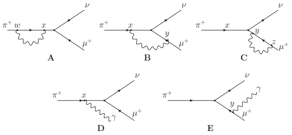


Figure 3: Diagrams for QED corrections to meson leptonic decay. Diagram

Accomplishments:

QED: π, K masses, and leptonic width diagram A.

γ W-box diagram contribution to neutron β decay.

PhysRevD.106.074510: $0\nu2\beta$ for $\pi^- \to \pi^+ e^+ e^-$

PhysRevLett.128.172002: two photon exchange contribution to muonic-hydrogen Lamb shift

Proposal objectives:

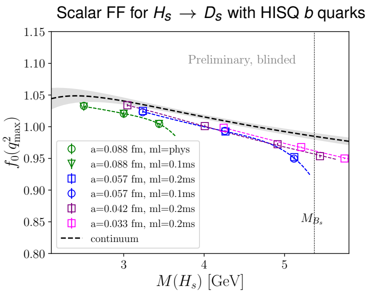
QED corrections to masses: π, K, n, p.

Other diagrams for leptonic decays (handle IR div.)

Proton & neutron hadronic tensor

QED corrections to HVP for muon g-2

Semileptonic $B \to D^*$ and $B_s \to D_s^*$ with HISQ quarks



Request is to extend the current FNAL/MILC calculations of semileptonic decays to include the decays $B \to D^*_{(s)}$.

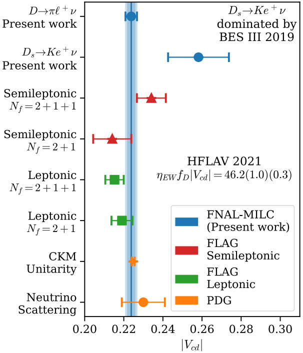
Extend techniques used to compute f_B with HISQ bottom quarks to SL B decays.

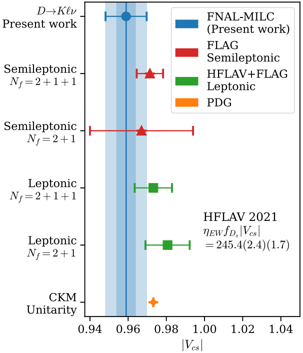
Objectives include SM determination of $|V_{cb}|$ and $R_{\tau/\ell}(D^*_{(s)})$ in combination with experiment.

New: Publication arXiv:2301.09229 analysis of $D \to \pi$, $D \to K$, and $D_s \to K$.

Full error budgets, blinded analysis. Highlights $\Rightarrow$

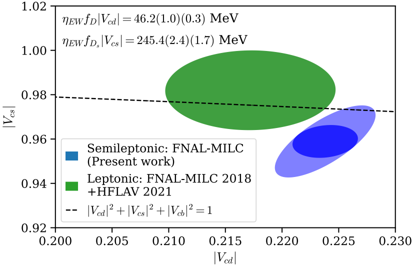
Second row CKM and unitarity – Fermilab MILC





Results after unblinding the *D*-decay analysis.

Outer / inner blue band shows total uncertainty with / without QED uncertainty.



Error elipses comparing Fermi-MILC results from SL decays to leptonic decays.

Proposals with HISQ lattices

Scale setting on HISQ lattices

Priority for Fermilab MILC muon g-2 project.

Scales valuable to entire community using HISQ lattices.

Better statisics for gradient flow scales w_0, and $\sqrt{t_0}$.

New: absolute scale from $m(\Omega^-)$ including leading EM effects.

$\Rightarrow$ talk

Lattices for precision f_K, f_π, and $f_+^{K\pi}(0)$

Refine first-row CKM unitarity tests.

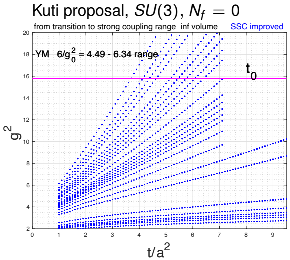
Proposal: Compute ME on re-tuned physical-mass lattices at $a \approx 0.12$ and 0.09 fm.

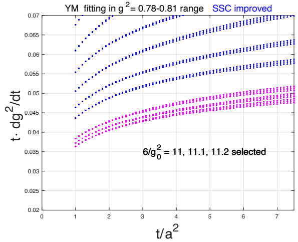
Progress: Generated set of 0.09 lattices with simulation $m_s' \leq 0.6 m_s$ useful for systematics – a community resource.

New results will help fully resolve LECs in combined continuum and $SU(3)$ χPT fits.

$\Rightarrow$ talk

Strong coupling from gradient flow





Compute $\Lambda_{\overline{MS}}$ in theories including $N_f = 3$ QCD.

Complementary proposals from Kuti and Hasenfratz ⇒ talk.

Define renormalized flow coupling, and beta function ($Vol \to \infty$)

$$g^2_{\rm GF}\left(t/a^2;\beta\right) = \mathcal{N} t^2 \left\langle E \right\rangle_{t;\beta},$$

$$\beta\left(g^2_{\rm GF}\right) = -t\,\frac{d}{dt}\,g^2_{\rm GF}.$$

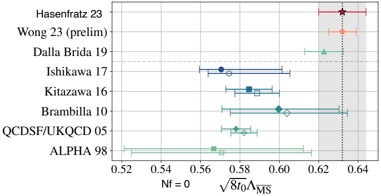
Lattices with different β to connect perturbative region to long-distance $g^2_{\rm GF}\left(t_0/a^2\right) = 15.8$ at the distance scale t_0.

USQCD

Flow coupling results and plans

Pure YM

Hazenfratz, arxiv:2303.00704



Wong, *et al.*, arXiv:2301.06611
Hasenfratz, *et al.*, arXiv:2303.00704

Flow results agree, but are in tension with other methods.

Hasenfratz plans

First extend $N_f = 2$ results before returning to $N_f = 3$. BNL CPU-only resources may not be sufficient to do both.

Kuti plans

Continue with $N_f = 3$ with a focus on stronger coupled runs for better statistics.

USQCD

Summary

Project goals are well aligned with USQCD's physics objectives and the needs of the experimental programs.

These projects continue to show excellent progress towards their objectives.

For many projects, both USQCD and leadership compute resources are critcal to meeting their goals.