SPC Report: Spectroscopy

USQCD All-Hands Meeting

April 20-21, 2023 @ Zoom

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for the USQCD Scientific Program Committee

@BrookhavenLab

Proposals covered in this section

1. **QCD + QED studies [Continuation]**
   - PI: Luchang Jin
   - *Presented at USQCD AHM 2022.*

2. **Nuclear Physics from the Standard Model [Continuation]**
   - PI: Phiala Shanahan [NPLQCD Collaboration]
   - *Presented at USQCD AHM 2022.*

3. **Novel anisotropic pure gauge simulations and the spectrum of anisotropic staggered quarks [Continuation]**
   - PI: Yannis Trimis

4. **Resonances in QCD and their Couplings from Anisotropic Clover Lattices [Continuation]**
   - PI: Robert Edwards [The Hadron Spectrum Collaboration]
   - Presentation by Arkaitz Rodas, 4:10PM EDT

5. **Scale setting studies on the MILC HISQ ensembles [Continuation]**
   - PI: Alexei Bazavov [Fermilab Lattice and MILC Collaborations]
   - Presentation by Yin Lin, 4:25PM EDT

QCD+QED Studies [Jin]

Proposal has multiple goals: EF+**NP**

- QED corrections to hadron masses, including the pion, kaon, **proton and neutron**
- QED corrections to the pion/kaon decay amplitude
- QED corrections to nucleon β decay and gA in neutron β decay

Continuation from last year. No change in methodology.

- Infinite volume reconstruction (IVR) method to eliminate all power-law suppressed finite-volume effects caused by massless photon. [X. Feng and L. Jin, 2019]
- Field sparsening method to reduce cost for disk/tape storage and contractions. [Detmold et al. 2019, Li et al 2021]
- **Improved performance of their automatic contraction code.**

Proposed Calculations:

- QED corrections to pion and kaon leptonic decay using the new 48I DWF ensemble.
- QED correction to the nucleon β decay and gA in neutron β decay using 32Dfine DWF ensembles.

Request: 5.12 M KNL core-hours on the BNL KNLs.

Alignment with USQCD program and NP/HEP experiments: flavor physics, Muon g-2

QCD+QED Studies [Jin]

Accomplishments using last allocation

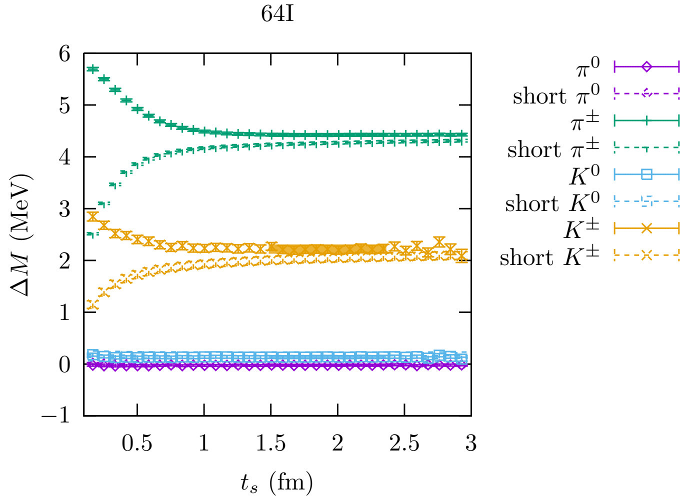

Figure 2: Results of the QED correction to meson mass with the 64I ensemble using the infinite volume reconstruction method. The t_s dependence of the results is shown. Plateau is reached for large enough t_s to suppress the hadronic excited state effects while still satisfies $t_s \lesssim L$ to keep the finite volume effects under control.

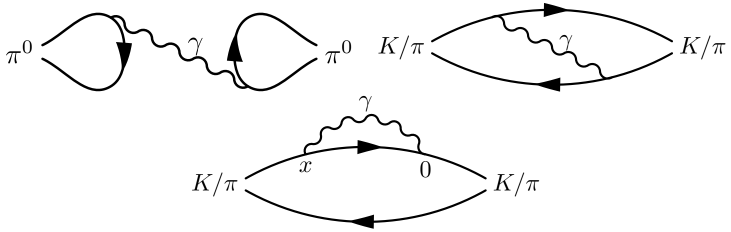

Figure 1: Diagrams for QED corrections to pion and kaon masses, some additional disconnected diagrams are not included and not shown.

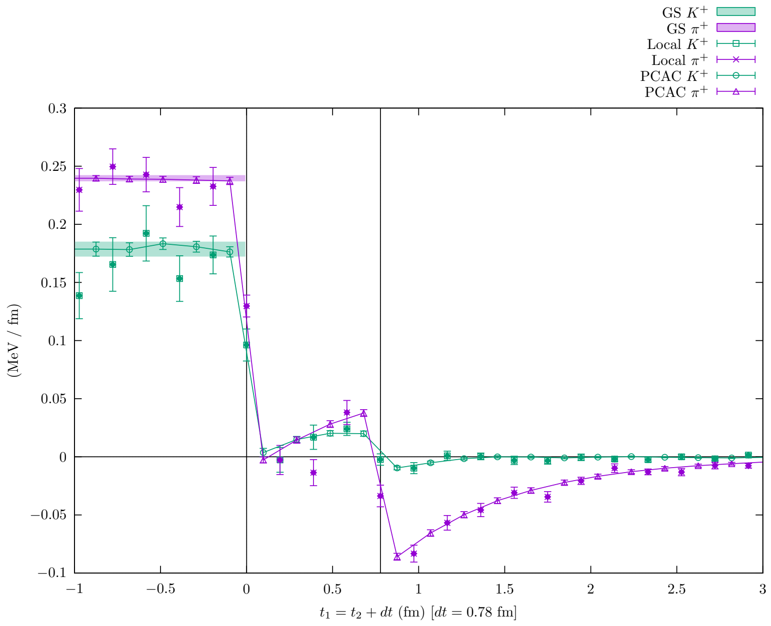

Figure 4: Results of the matrix elements for the diagram A in Fig. 3 with the 24D ensemble. The t_1 dependence of the results is shown.

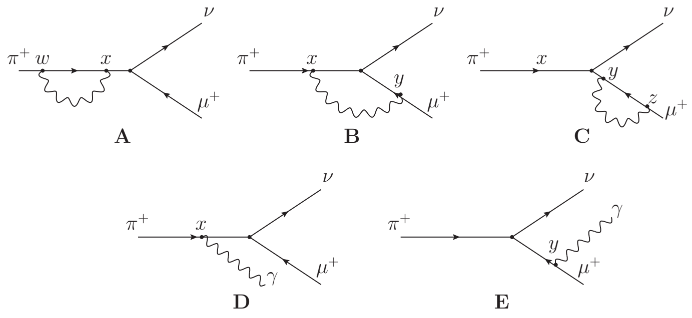

Figure 3: Diagrams for QED corrections to meson leptonic decay. Diagram C and E only depends on the meson decay constant.

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Nuclear Physics from the Standard Model [Shanahan]

Goals

- Calculate from first principles the **spectroscopy and properties** of light **nuclear and hypernuclear** systems, particularly hyperon-nucleon (YN) and hyperon-hyperon (YY)
- Enable the calculation of **baryon-baryon scattering phase shifts** and **binding energies**
- Provide crucial input to address “hyperon puzzle”, and to searches of BSM physics using nuclear targets

This year’s proposal:

- Continue *variational* calculation of the spectrum of **octet- octet two-baryon systems** using sparse propagator techniques, with multiple boosts, source and sink interpolating operators.
- Pion mass 170 MeV, two lattice volumes $48^3 \times 96$ ($4.5^3 \times 9$ fm^4), and $64^3 \times 128$ ($6^3 \times 12$ fm^4)
- Isotropic clover-improved fermion action, Luscher-Weisz gauge action

Request: 43K K80 GPU-hours + 86K A100 GPU-hours

Alignment with USQCD program and NP/HEP experiments: understanding light nuclei from first principles. BSM constraints for ALICE experiment.

Nuclear Physics from the Standard Model [Shanahan]

Accomplishments using last allocation

- Finished proposed calculations of two-baryon spectroscopy at two lattice volumes at the pion mass 170 MeV
- Additional propagators generated using other resources, which will be used for contractions using this year's allocation.

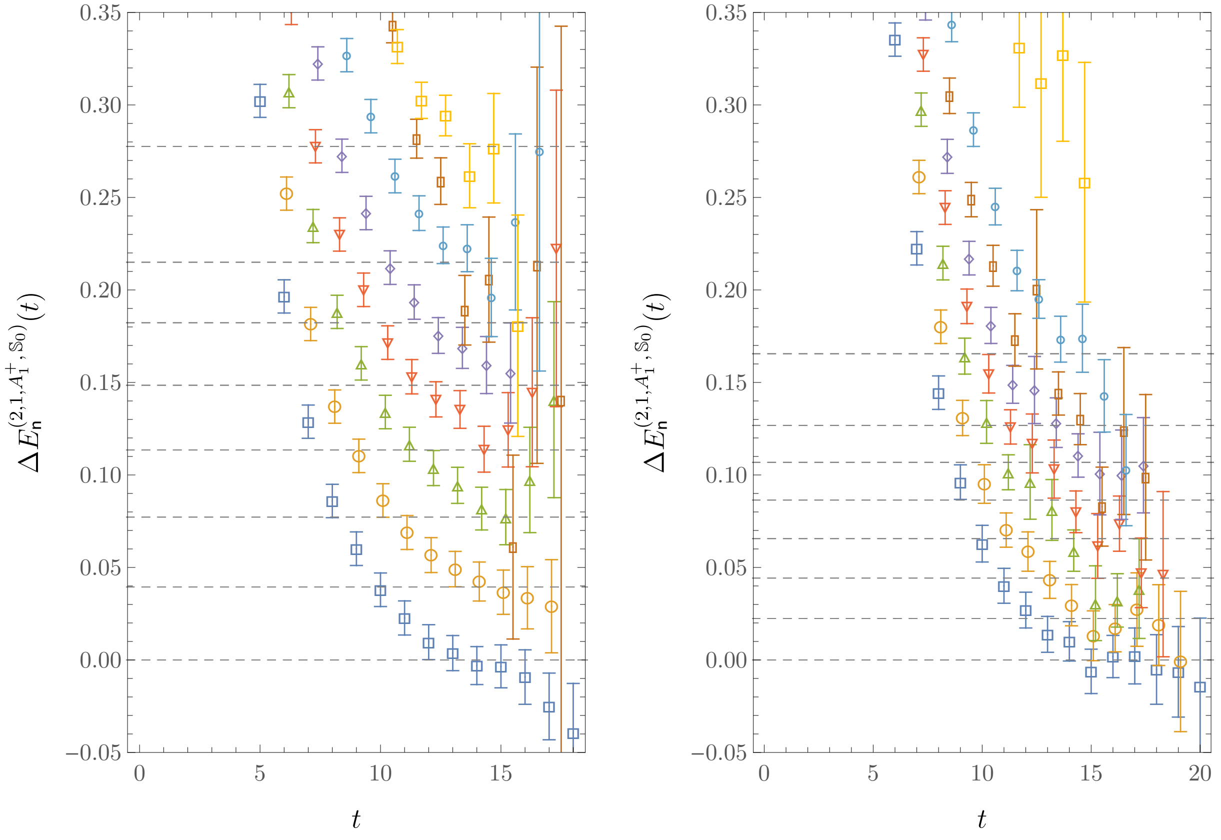

FIG. 1: Preliminary variational analysis on the (left) $L^3 \times T = 48^3 \times 96$ ensemble with $m_\pi \sim 170$ MeV with data from 670 configurations, and (right) on the $L^3 \times T = 64^3 \times 128$ ensemble with $m_\pi \sim 170$ MeV with data from 300 configurations. The figures show GEVP effective FV energy shifts obtained with one interpolating-operator set, labelled $\mathbb{S}_0^{(2,1,A_1^+)}$ in Ref. [19] (our analysis at $m_\pi = 806$ MeV). Non-interacting two-nucleon FV energy shifts $2\sqrt{M_N^2 + \mathfrak{s}(2\pi/L)^2} - 2M_N$ with $\mathfrak{s} \in \{0, 1, 2, 3, 4, 5, 6, 8\}$ are shown as dashed gray lines.

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Novel anisotropic pure gauge simulations and the spectrum of anisotropic staggered quarks [Trimis]

Goals:

- Lay the foundation for generation of fully dynamical anisotropic HISQ (aHISQ) ensembles
- Understand spectrum with anisotropic staggered quarks and taste-breaking effects
- To calculate heavy quarkonia spectral functions at finite T, with accompanying zero-T ensembles for tuning.

Methodology:

- Start with pure gauge ensembles
- Set lattice spacing with gradient flow with different flow anisotropies
- Calculate spectrum of non-local pions with aHISQ to study taste-breaking

Proposed Calculations:

- Generation of four new pure gauge ensembles
- Exploratory generation of dynamical aHISQ ensembles

Request: 6.54 M Sky-core-hours

Alignment with USQCD program and NP/HEP experiments: RHIC and LHC

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Novel anisotropic pure gauge simulations [Trimis]
Accomplishments from last allocation

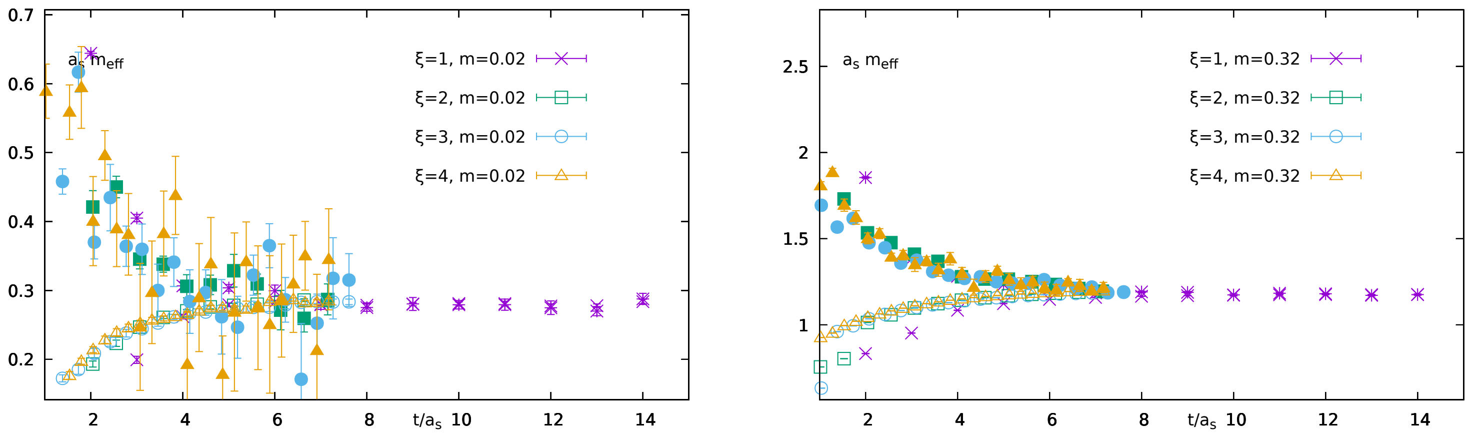

Figure 1: Effective mass of the Goldstone pion for different anisotropies at **zero** hadron momentum. The spatial lattice spacing is about $a_s = 0.16$ fm, the bare quark masses are $am = 0.02$ (left) and $am = 0.32$ (right). The plateau is reached from above by the point-point/point-point correlator (filled symbols) and from below by the point-point/corner wall-point correlator (open symbols).

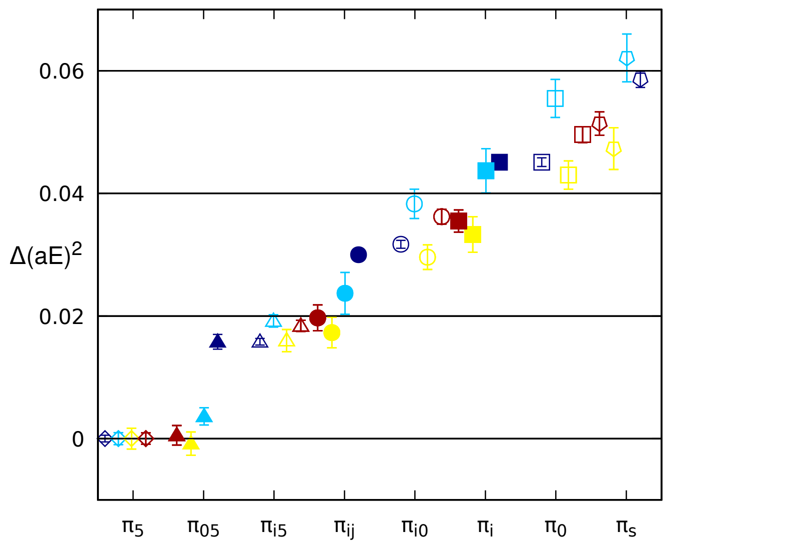

Figure 2: Non-local pion splittings as function of anisotropy.

Resonances in QCD and their Couplings [Edwards]

In QCD, most hadronic states are resonances

- Short-lived
- Multiple decay modes possible

Lattice calculations of resonances are particularly challenging at lighter quark masses

- More decay channels will be allowed, including many-hadron channels => more interpolating operators
- Most lattice calculations to date are done with heavy pion masses to avoid three-body dynamics

Proposed this year:

- Continuing calculations of resonance properties on $48^3 \times 512$ lattices at 170 MeV pion
- Dynamical anisotropic clover fermions

Request: 1.6M RTX 2080 GPU hours, 0.41M AMD MI-100 hours, and 53M KNL core-hours

Alignment with USQCD program and NP/HEP experiments: Hadron Spectroscopy, GlueX, CLAS12, COMPASS

More Details by Arkaitz Rodas, 4:10PM EDT

Scale setting studies on the MILC HISQ ensembles [Bazavov]

Goals:

- Better determination of the lattice scale for MILC HISQ ensembles with reduced statistical and systematic errors (through gradient flow scales)
- Leading-order EM correction to the Ω baryon mass on the physical mass ensembles (also feeds into the scale determination)

Proposed Calculations:

- Measure the gradient flow scales on the retuned physical mass a = 0.09 fm ensemble
- Compute the electromagnetic corrections of $M_\Omega a$ on the $a \approx 0.09, 0.12$ fm physical quark mass ensembles

Request: 6.1 M Sky-core-hours

Alignment with USQCD program and NP/HEP experiments: Precision flavor physics, g-2

More Details by Yin Lin, 4:25PM EDT

Summary

- Hadron and nuclear spectroscopy are fundamental lattice QCD calculations.
- However, challenges remain to achieve precise lattice QCD results.
  - **Multi-baryon systems**: signal-to-noise issues, complex contractions
  - **EM effects**: theoretical and numerical methodologies
  - **Resonances**: multi-channel decays, signal-to-noise issues
  - Control of **statistical and systematic errors**
- USQCD proposals continue to tackle these issues.