Overview of Scientific Program

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LQCD extension III Review
Cambria Rockville Hotel | July 9–10, 2019

junior faculty
postdoc

USQCD Whitepapers 1

- Opportunities for Lattice QCD in **Quark and Lepton Flavor** Physics (C. Lehner, S. Meinel, T. Blum, N. H. Christ, A. X. El-Khadra, M. T. Hansen, A.S. Kronfeld, J. Laiho, E. T. Neil, S.R. Sharpe, R.S. Van de Water) [arXiv:1904.09479]

- Lattice Gauge Theory for Physics **Beyond the Standard Model** (R. C. Brower, A. Hasenfratz, E. T. Neil, S. Catterall, G. Fleming, J. Giedt, E. Rinaldi, D. Schaich, E. Weinberg, O. Witzel) [arXiv:1904.09964]

- Lattice QCD and **Neutrino**-Nucleus Scattering (A. S. Kronfeld, D. G. Richards, W. Detmold, R. Gupta, H.-W. Lin, K.-F. Liu, A. S. Meyer, R. Sufian, S. Syritsyn) [arXiv:1904.09931]

- The Role of Lattice QCD in Searches for **Violations of Fundamental Symmetries** and Signals for New Physics (V. Cirigliano, Z. Davoudi, T. Bhattacharya, T. Izubuchi, P. E. Shanahan, S. Syritsyn, M. L. Wagman) [arXiv:1904.09704]

USQCD Whitepapers 2

junior faculty
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- **Hadrons and Nuclei** (W. Detmold, R. G. Edwards, J. J. Dudek, M. Engelhardt, H.-W. Lin, S. Meinel, K. Orginos, P.E. Shanahan) [arXiv: 1904.09512]

- **Hot-dense** Lattice QCD (A. Bazavov, F. Karsch, S. Mukherjee, P. Petreczky) [arXiv:1904.09951]

- Status and Future Perspectives for Lattice Gauge Theory **Calculations to the Exascale** and Beyond (B. Joó, C. Jung, N. H. Christ, W. Detmold, R. G. Edwards, M. Savage, P. E. Shanahan) [arXiv:1904.09725]

- European Journal of Physics A has invited USQCD to publish all seven in a topical issue (which we're doing).

Science Talks

- Agenda organized by physics and similar details of computations:
  - *Quark and Lepton Flavor Physics* – Ruth Van de Water
  - *Neutrino-Nucleus Scattering* – Andreas Kronfeld
  - (*Violations of*) *Fundamental Symmetries* – Zohreh Davoudi
  - (*Lattice Gauge Theories*) *Beyond the Standard Model* – Ethan Neil
- Here, illustrate how the proposed research program aligns with the five Science Drivers of the Particle Physics Project Prioritization Panel (P5).
  - (Unboxed text on next six slides cut and pasted from P5 report.)

P5 Report's Science Drivers

QvFB Use the Higgs boson as a new tool for discovery.

vF Pursue physics associated with neutrino mass.

FB Identify the new physics of dark matter.

B Understand cosmic acceleration: dark energy and inflation.

QvFB Explore the unknown: new particles, interactions, and physical principles.

These topics are covered in talks on Q = quark & lepton flavor; ν = neutrino; F = fundamental symmetries; B = BSM LGT.

Higgs Boson

QvFB

- The recently discovered Higgs boson is a form of matter never before observed, and it is mysterious.
  - ⭐ What principles determine its effects on other particles?
  - ⭐ How does it interact with neutrinos or with dark matter?
  - Is there one Higgs particle or many?
  - ⭐ Is the new particle really fundamental, or is it composed of others?
- ⭐ The Higgs boson offers a unique portal into the laws of nature.

m_b, m_c, & α_s; composite Higgs; σ terms; PDFs

Neutrino Physics

vF

- Future experiments will address the questions:
  - ⭐ What is the origin of neutrino mass?
  - ⭐ How are the masses ordered (referred to as mass hierarchy)?
  - ☆ What are the masses?
  - ⭐ Do neutrinos and antineutrinos oscillate differently?
  - ⭐ Are there additional neutrino types or interactions?
  - ⭐ Are neutrinos their own antiparticles?

Neutrino-nucleon & neutrino-nucleus matrix elements

Dark Matter

FB

- Dark matter is presumed to consist of one or more kinds of new particles.

- The properties of these particles, which are all around us, are unknown. Dark matter represents a bizarre shadow world of fundamental particles that are both omnipresent and largely imperceptible.

⭐ Experiments are poised to reveal the identity of dark matter, a discovery that would transform the field of particle physics, advancing the understanding of the basic building blocks of the Universe.

Composite DM; nucleon & nuclear matrix elements

Dark Energy & Inflation

B

- What is driving the accelerated expansion of the Universe today?
- Is it caused by the energy in the vacuum, the so-called cosmological constant? If so, why is the cosmological constant (one form of dark energy) so small?
- Is cosmic acceleration driven by a different type of dark energy that evolves with time, or is it due to a modification of Einstein's theory of gravity, general relativity?
- What drove the apparent accelerated expansion during the inflationary epoch at ultra-high energies?

Thermodynamics of composite DM models

Explore the Unknown

QvFB

- There are clear indicators of new phenomena awaiting discovery beyond those motivating the other four drivers.
- Particle physics is a discovery science defined by the search for new particles and new interactions, and by tests of physical principles.
- The tools for this search are varied and include very high-energy beams of protons and electrons, intense beams of protons, and cosmic sources of ultra high-energy particles.
- The searches take two basic forms: directly producing and indirectly detecting evidence for new particles.

Numerous lattice-QCD calculations

Five HEP Milestones

- As listed in Sec. IV of the proposal, we present five science milestones:
  - Complete calculations of the HVP and HLbL contributions to muon *g*–2 with the required precision on the timescale of Fermilab E989.
  - Continue to sharpen the search for new physics in the quark-flavor sector.
  - Develop a program of precision nucleon matrix elements with comprehensive error budgets.
  - Continue the exploration of gauge theories other than QCD.
  - Provide a platform for innovation on these and further relevant areas.

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The science talks address the milestones indirectly;
the 2:35 PM talk explicitly.

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Questions?