Snowmass LOIs on Lattice Gauge Theory

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USQCD Collaboration

- USQCD is a federation of science collaborations:
  - acquire and coordinate computing resources for U.S. community of (numerical) lattice gauge theorists.
- USQCD Executive Committee will submit one LOI (to CompF02 and TF05), drawing attention to seven whitepapers that appeared in 2019 (being drafted).
- Constituent collaborations and groups of individuals are being explicit encouraged to submit LOIs.

Guides to the Slides

- Collaboration names imply a collaboration is working together.

- Personal names imply groupings outside of collaborations.

- Planned: under discussion but no draft yet.

- Drafting: being written

- Review: draft done, co-authors polishing

- Submitted

LOIs for CompF02:

Theoretical Calculations and Simulation

Algorithms and Software in Support of Computational High-Energy and Nuclear Physics at the Exascale and Beyond

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- Carleton DeTar *et alia* (LatticeQCD ECP software task); drafting.
- Exascale challenge:
  - novel architectures, multiple vendors creates a software portability problem;
  - complex and evolving hardware and compiler stacks create an optimization challenge.
- Listing of USQCD code bases and libraries for NP & HEP lattice QCD calculations and BSM exploration.
- ECP readiness effort: QUDA, Grid, *etc*. porting—scale of effort.
- Looking beyond ECP: importance of continued support for software and algorithm development/improvement (*cf*. April 2020 draft of Giles report).

Multi-scale Solvers

- Rich Brower *et alia* (LatticeQCD ECP solver task); planned.

- In the context of the Exascale Computing Project and, in particular, in collaboration with NVIDIA colleagues.

- A central part of lattice QCD is to obtain a Green function of the (lattice) Dirac operator:

  - multi-scale slowing down as $m_q \to m_{\text{up}},\ a \to 0$;

  - success and prospects of, *e.g.*, multi-grid methods.

Other ECP possibilities

- Norman Christ *et alia* (LatticeQCD ECP CSD task); considered:
  - the Markov chain for generating lattice gauge fields slows down as $a \rightarrow 0$ (beyond Dirac solver issues).
- Robert Edwards *et alia* (LatticeQCD ECP contractions task); considered:
  - hadron correlators for nuclei become prohibitive, growing as $\sim(3A)^2$.

LOIs for CompF02 ⊕ Lattice Gauge Theory

Computational Requirements

- Peter Boyle & RBC/UKQCD collaborations; planned.

- CompF2 ⊕ TF05.

- Computational requirements (including on going software and algorithm development) for $n_f = 2{+}1{+}1$ chiral-fermion program with $a^{-1} \approx 3$–5 GeV.

- Make use of improvements from the existing ECP software, solvers, and critical slowing down program, but require an on-going investment in these areas to exploit HPC ten years from now.

- The investment in people is important, and career paths to long term positions in labs are required for retention of expertise.

- Xiao-Yong Jin, Sam Foreman, James Osborn; planned:
  - Machine Learning techniques for lattice QCD, mainly on generalized HMC algorithms for generating gauge configurations (CompF2 ⊕ CompF3 ⊕ CompF6).
- Tanmoy Bhattacharya, Rajan Gupta, Boram Yoon, & non-lattice collaborators at LANL; planned:
  - ML, QIS for lattice QCD (CompF2 ⊕ CompF3 ⊕ CompF6).
- Phiala Shanahan & MIT colleagues; planned:
  - FPGA hardware for lattice field theory (CompF2 ⊕ TF05).

See, *e.g.*, T. Janson @ ACAT 2017.

LOIs for Lattice Gauge Theory ⊕ CompF02

- Tanmoy Bhattacharya, Rajan Gupta, Boram Yoon; planned:
  - neutron EDM from the operators up to dimension 6 using Lattice QCD (RF3 ⊕ CF2 ⊕ TF05 ⊕ CompF2);
  - scalar and tensor charges of the neutron including isospin breaking and momentum (EF05 ⊕ EF10 ⊕ NF05 ⊕ CF1 ⊕ TF05 ⊕ CompF2)
  - axial charges and form factors (NF05 ⊕ NF09 ⊕ CF1 ⊕ TF05 ⊕ CompF2)
  - neutrinoless double beta decay (NF03 ⊕ NF05 ⊕ RF4 ⊕ TF05 ⊕ TF11 ⊕ CompF2)
  - radiative corrections for semileptonic form factor (RF2 ⊕ TF05 ⊕ AF5 ⊕ CompF2).

Lattice QCD ⊕ Nuclear Many-Body Theory

- Mike Wagman and collaborators at Fermilab, ANL, LBNL; being drafted.
  - Idea: combine lattice QCD calculations of nucleon properties with nuclear many-body theory (Green-function MC, spectral functions, ...).
  - LOI express interest in developing this idea from wishful thinking (as in, e.g., USQCD WP) into a real framework, making it possible to identify targets of opportunity for calculations and further theory development.
  - QE, resonance region, SIS, DIS.
- Collaborators include nuclear theorists, lattice-QCD experts, and neutrino phenomenologists.
- Connect framework to generators.

LOIs for Lattice Gauge Theory + Other CompF

- Phiala Shanahan (MIT) & NYU, DeepMind colleagues; planned.
    - Machine learning for first-principles theory calculations (CompF3 ⊕ TF05).
- Tanmoy Bhattacharya and collaborators at LANL (lattice & non-lattice); planned.
    - HEP-QIS (TF10 ⊕ CompF6).
- Yannick Meurice, Simon Catterall, and Judah Unmuth-Yockey; two LOIs; both under review.
    - Tensor RG methods for lattice field theories (CompF6 QC ⊕ TF05 LGT ⊕ TF10 QIS).
    - Propose access to quantum computing facilities, coordinated as in USQCD, but without the hardware component (CompF6 QC ⊕ TF05 LGT ⊕ TF10 QIS).

LOIs for Lattice Gauge Theory + Other TGs

Fermilab Lattice and MILC Collaborations

- Future Fermilab/MILC program in quark-flavor physics (Carleton DeTar = POC); TF05 ⊕ RF1 ⊕ RF2; under review.

- Future Fermilab/MILC plans for muon g–2 (Aida El-Khadra = POC); TF05 ⊕ RF3; planned.

- Status of quark masses and plans for strong coupling (Andreas Kronfeld = POC); TF05 ⊕ EF01; being drafted.

- Future Fermilab/MILC plans for nucleon matrix elements for neutrino physics (Andreas Kronfeld = POC); TF05 ⊕ TF11 ⊕ NF06; planned.

- Prospects for inclusive *B* decay amplitudes (Will Jay, Tom DeGrand = POCs); TF05 ⊕ RF1; planned.

- Phiala Shanahan & MIT colleagues; planned.
  - Gluon structure of hadrons and nuclei for TF05 ⊕ EF06;
  - Some emphasis on EIC applications.
- NPLQCD Collaboration (Phiala Shanahan = POC); planned.
  - Constraints on electroweak matrix elements from lattice QCD for EF04 and TF05
- NPLQCD Collaboration (Mike Wagman = POC); planned.
  - Lattice QCD inputs for neutrino-nucleus scattering (TF11 ⊕ NF06), including multi-nucleon matrix elements, pion production, ingredients for the resonance region, ...

Towards global fits for three-dimensional nucleon structure from lattice QCD

- Chris Monahan, Kostas Orginos, Luigi Del Debbio (and others); being drafted.
- TF05 ⊕ EF06
- Progress and prospects in lattice calculations of collinear hadron structure:
  - challenge of the ill-posed inverse problem for reconstructing PDFs from lattice data;
  - connections to the global fitting paradigm;
  - need for theoretical calculations of GPDs;
  - opportunities and challenges for lattice-QCD calculations of three-dimensional, x-dependent hadron structure.

RBC/UKQCD Collaboration

- Rare $\Delta S = 1$ or 2 processes (Norman Christ = POC); RF2 ⊕ TF05 ⊕ TF06; planned.
  - Direct CP violation from ε′ including the important EM and quark-mass isospin breaking corrections to two-pion kaon decay, achieving 10% over-all accuracy or below.
  - Indirect CP violation from ε, including long-distance effects, with sub-percent accuracy.
- The K_L–K_S mass difference to few-percent accuracy.
- $K^+ \to \pi^+\nu\nu$ decay including long-distance effects resulting in sub-percent accuracy.
- Calculation of the two-intermediate-photon background to $K_L \to \mu^+\mu^-$ allowing a new 10% test of the Standard Model.

Questions? Comments!