Quantum Simulation for High Energy Physics

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Quantum Simulation for HEP

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Physics Drive

- Many important theoretical questions intractable for classical techniques
  - collider physics
  - neutrino physics
  - cosmology
  - early universe physics
  - quantum gravity
  - ...
- Quantum algorithms has potential to provide computationally feasible approaches to these problems
  - S-matrix or EFT scattering calculations
  - collective neutrino oscillations
  - non-equilibrium dynamics
  - bulk gravitational phenomena
  - probably many others

Underlying simulations

Advances in many fields are needed to make these problems accessible to quantum computers

- Fundamentally new field theory formulations
  - Turn infinite dimensional Hilbert space into finite dimensional
  - Find optimal ways to protect or utilize underlying symmetries
  - Understand systematic uncertainties given truncations used
- Algorithmic research
  - Efficient encoding of problems into qubits
  - Develop algorithms with tight and rigorous error bounds
  - Concrete algorithms to prepare and measure non-trivial states
- Utilize analog quantum computers
  - Certain problems might be better addressed on analog simulators
  - Map desired QFTs onto other analog quantum systems

Simulator requirements

- Hardware needs to get much better for realistic simulations
  - Is industry sufficient to provide this?
- Need wide variety of hardware
  - Pursue different techniques for digital computers
  - Development of analog simulators
- Need hardware that HEP can experiment with
  - This likely requires DOE funded hardware development
- Develop Error correction and noise mitigation techniques
  - Best techniques for HEP could be specific to our field
- For broad HEP participation, need high level compilers and HEP specific libraries
  - Some developments will happen anyways, but HEP needs to participate

Quantum Ecosystem

- Quantum computing requires expertise from many different areas, many of which are not part of traditional HEP research directions
  - Needs expertise that is not currently among HEP scientists
  - HEP needs to be involved in training of future workforce
  - Long term career prospects need to be developed and funded
- Industry will likely play critical role in many needed advances
  - Need good collaborations with industry partners
  - Important that HEP can shape direction of industry R&D

Conclusions and personal thoughts

- Quantum computing has had extremely rapid development over past years (not even mentioned in last Snowmass)
- Has potential to solve problems unimaginable using classical techniques
- Many fascinating problems to solve such as pure theory, algorithm and software development and hardware creation
- This is the time to define the future of this field, and make sure we can reap benefits
- Given interdisciplinary nature, field needs to establish new cross-cutting ways to train workforce and provide long term job prospects

Exciting times ahead, and even if you are not personally working in this field, please follow developments and support this field moving forward