CompF6 Report Summary

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Draft of the CF6 Report

• https://snowmass21.org/computational/start#report_drafts
Why is *quantum computing* interesting for HEP?

- A quantum computer is a programmable interface to quantum physics experiments.
  - *It is a tool for discovery, like a telescope, or a particle accelerator.*
- In HEP we face a set of **computational challenges** in where *the only practical path to solution requires the utilization of entanglement and superposition as algorithmic primitives.*
  - In particular, **scalable methods for accurately simulating quantum many-body systems are beyond the capabilities of classical computers.**
  - Additionally, quantum computers are anticipated to play a **strong role in future event generators**, speeding up matrix element calculations and even neutrino-nucleus cross section calculations.
  - Also, quantum computers may play an important role in **data analysis**, especially in tandem with quantum sensors and networks.
Simulating physics

- Quantum computing has the potential to revolutionize our ability to simulate physics. Quantum many-body simulation and lattice field theory in particular stand to gain.

- Daunting work program ahead though:
  - Need to understand interplay between theory errors and errors from the quantum computer, even as fault tolerance begins to come online. What is the “sweet spot” for ambitious applications?
  - Need to build error correction protocols into our calculations as well and progress calculations “up the ladder” of group complexity.
  - Need to fully understand how to leverage the capabilities of the hardware platforms available to us, including how to build specialized hardware for HEP calculations.

Figures courtesy of M. Savage (UW)
Quantum computers for data analysis & machine learning

- Classical data analyzed on a quantum computer is the most studied problem type.
  - Quantum computers may offer important benefits in data analysis, particularly in cases where combinatorics are a challenge (e.g., clustering, tracking).
  - Likely requires fault-tolerant quantum computers.

- Quantum data analysis on a quantum computer is another particularly exciting option - leverage quantum sensors or even the outputs of quantum computers running simulations where the data itself is naturally entangled and in a state of superposition.

"QQ" in action - courtesy of Q. Zhuang (U. of Arizona)
NQIA Centers & SQMS

- H.R. 6227 authorized $625,000,000 over five years for five DOE and two NSF national quantum centers.
- HEP hosts one of the Centers at Fermilab - The Superconducting Quantum Materials and Systems Center (SQMS)
  - HEP is also involved at the Quantum Science Center (QSC) hosted at ORNL, as well as Q-NEXT and QSA.
- Leverage HEP expertise in large scale projects and cryogenic engineering to construct large testbeds.
- Leverage decades of research into SRF resonators to create 3D architectures in the quantum regime.
  - Highest coherence quantum resonators ever demonstrated.
  - Ambitious quantum sensing program as well.

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Slide material courtesy of Anna Grassellino (FNAL)
Example Strategy @ QSC: Leverage HEP capabilities

Science targets: Topological quantum materials/computing, single photon detectors, microcalorimetry for dark matter searches. Engages condensed matter/materials capabilities of BES and ASCR.

highly multiplexed readout of cryogenic qubit/sensor arrays

Cryogenic qubit control systems

Low radiogenic background testing of quantum materials and sensors
We are in early days…

- There is an entire software stack to be built. Nobody reasons about classical algorithms using circuits anymore, but that is where we are in quantum.
  - Scientific applications will be a critical early driver in this process!
- There is a large diversity of hardware approaches and we don’t yet know what will scale best or be best suited to HEP problems - we need to have some exposure to all of them!

https://sqms.fnal.gov/research/
https://www.xanadu.ai/hardware