CompF6 Report Summary

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Snowmass 2022

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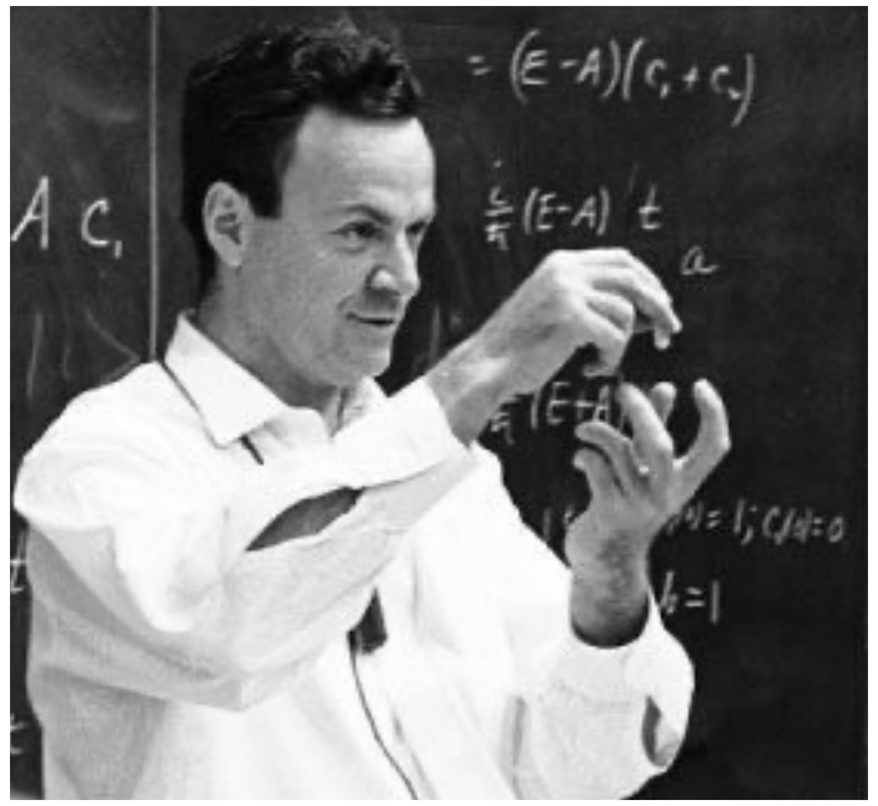
Draft of the CF6 Report

- https://snowmass21.org/computational/start#report_drafts

Why is *quantum computing* interesting for HEP?



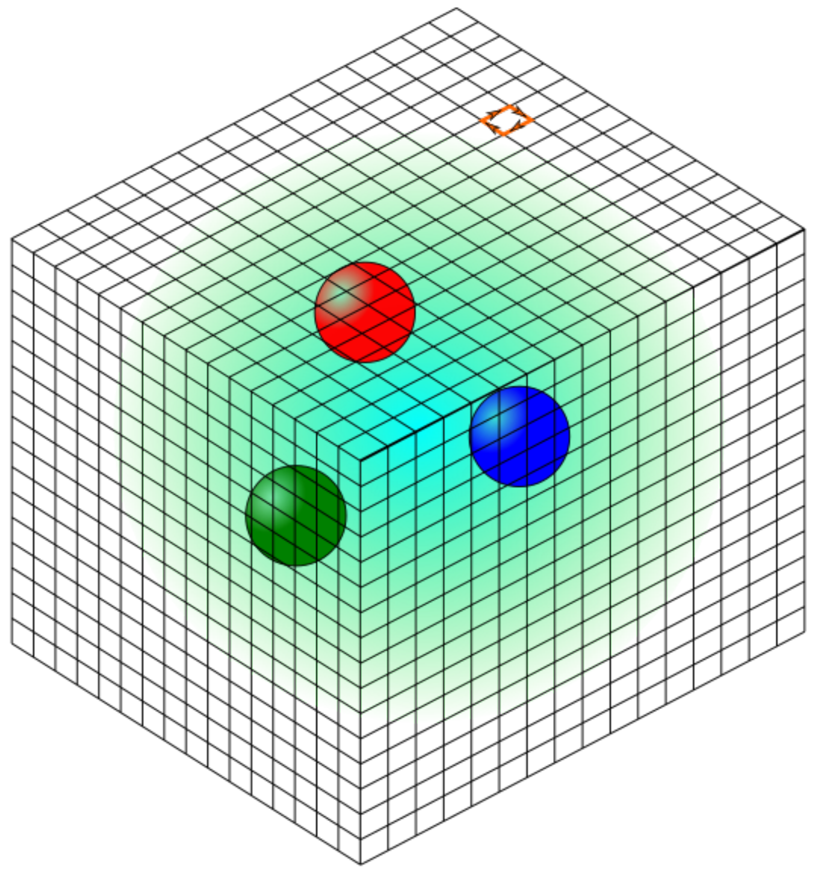


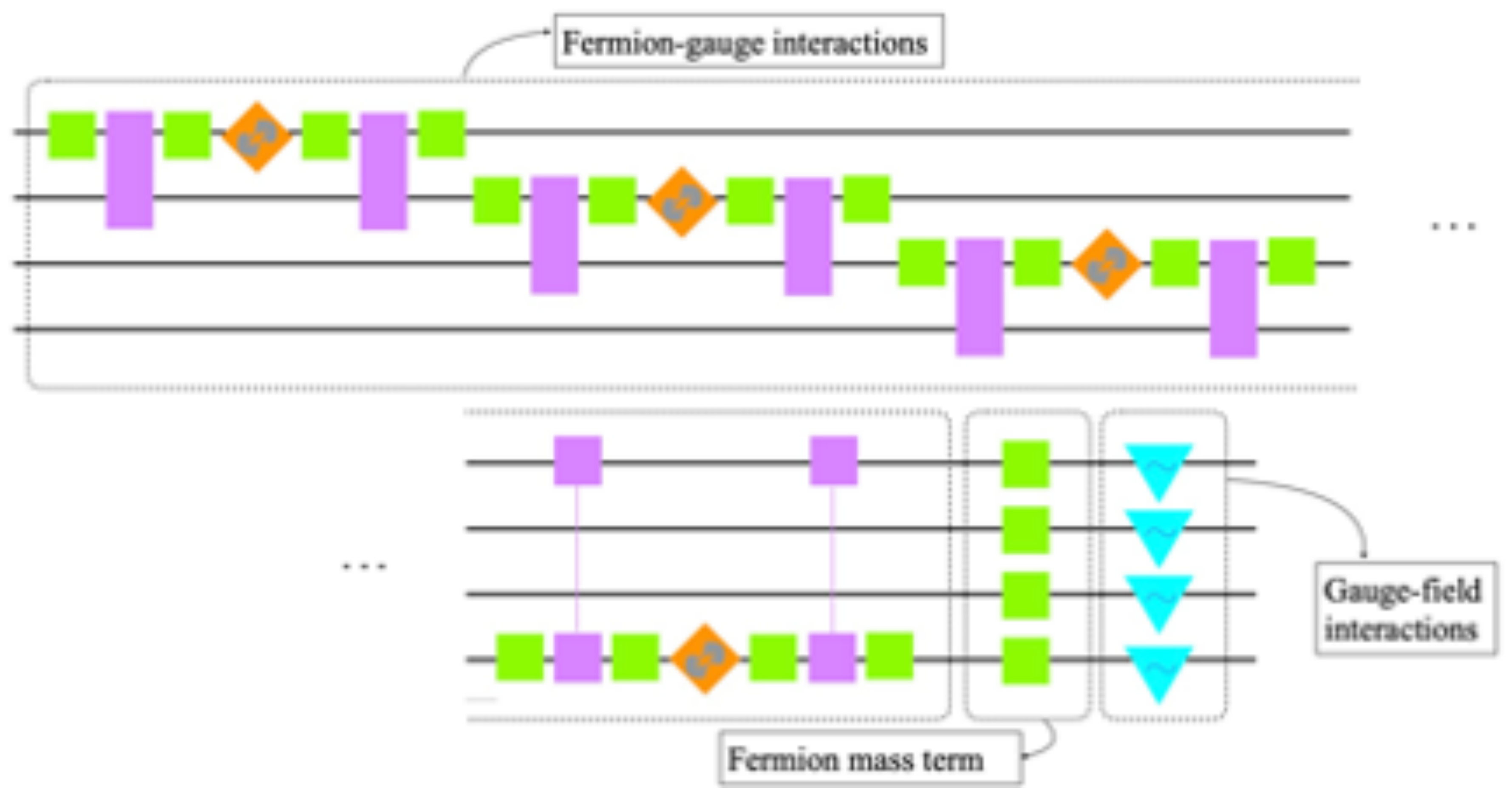
Figure courtesy of H. Lamm

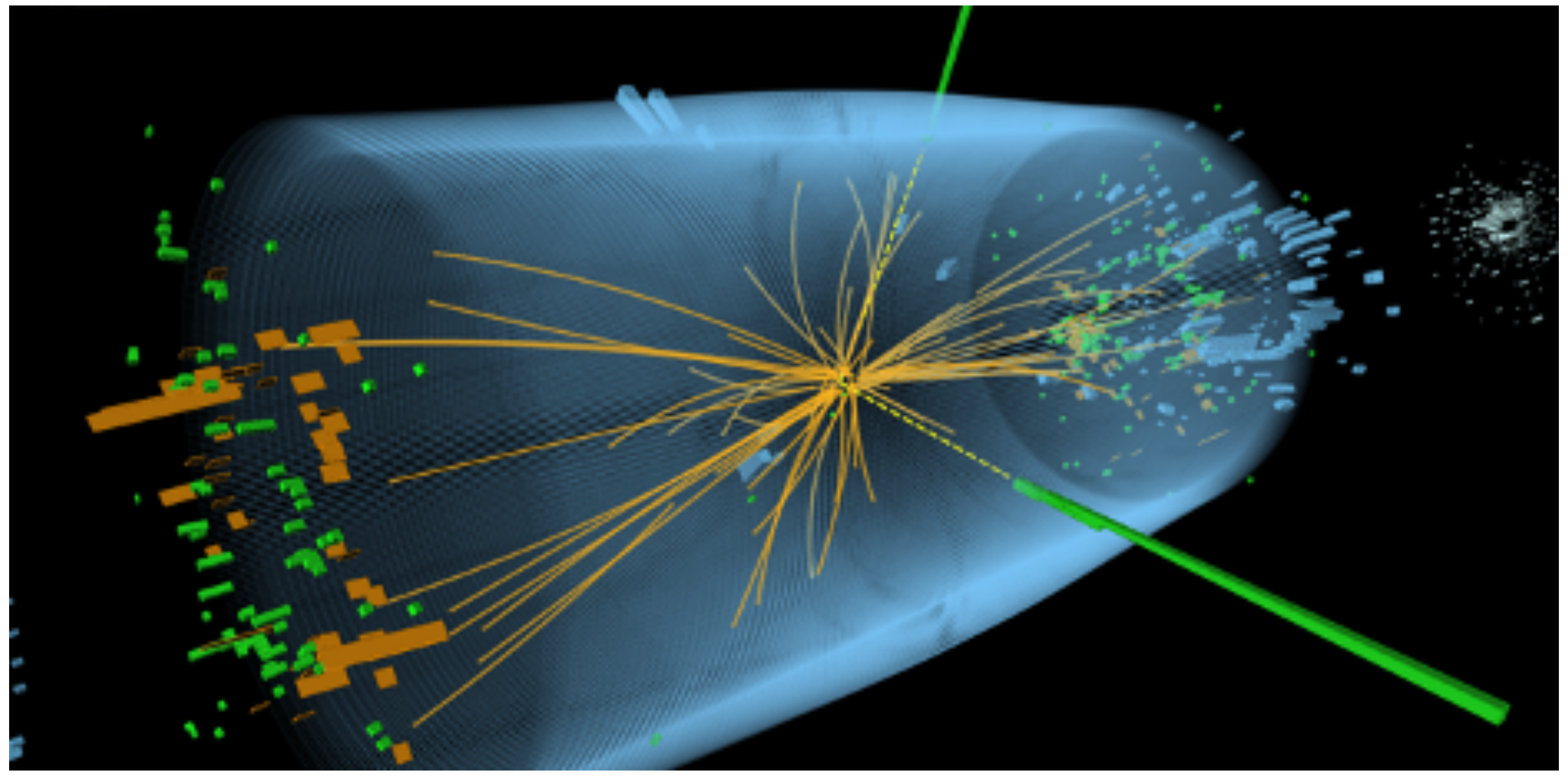
- **A quantum computer is a programmable interface to quantum physics experiments.**
  - ***It is a tool for discovery, like a telescope, or a particle accelerator.***
- In HEP we face a set of **computational challenges** in where ***the only practical path to solution requires the utilization of entanglement 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

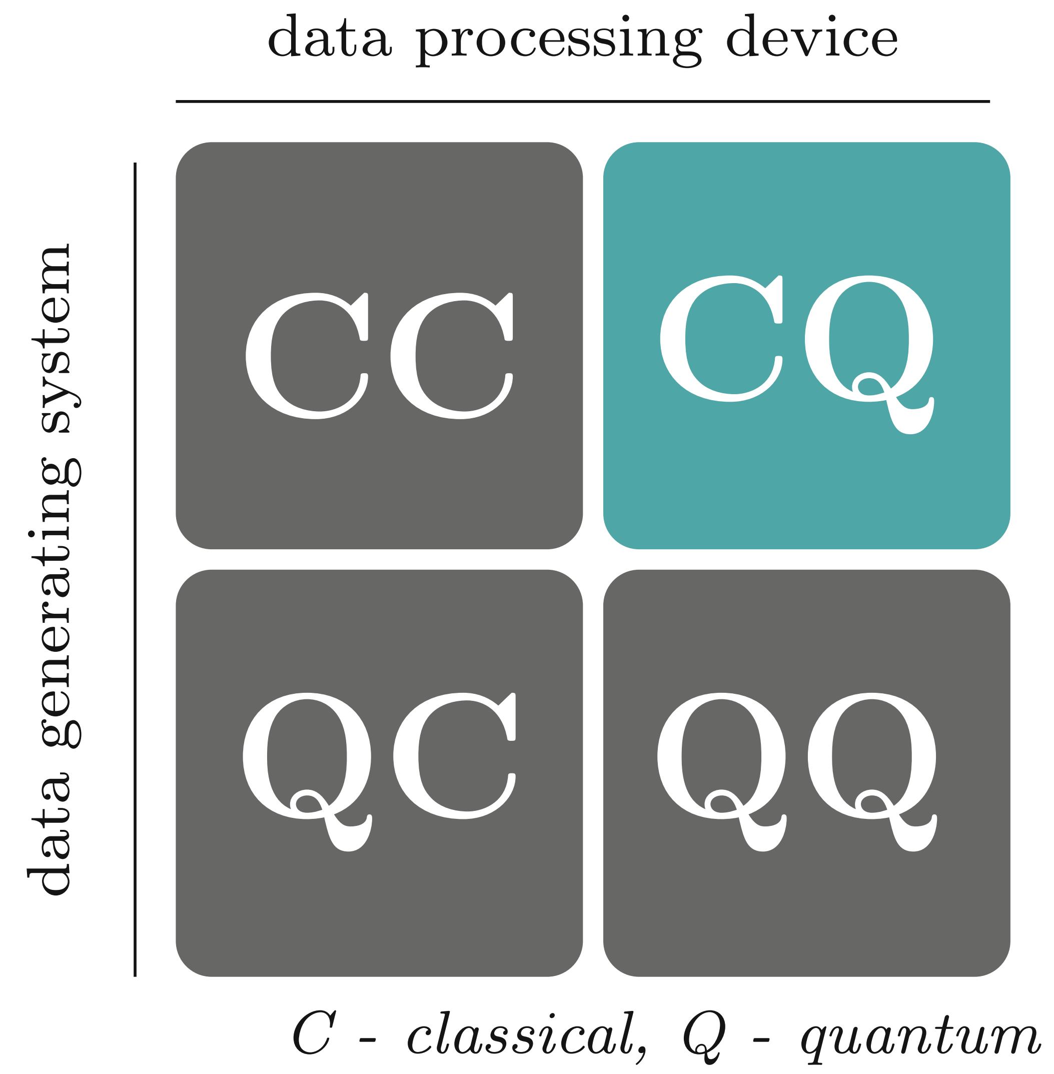
Figures courtesy of M. Savage (UW)

- 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.



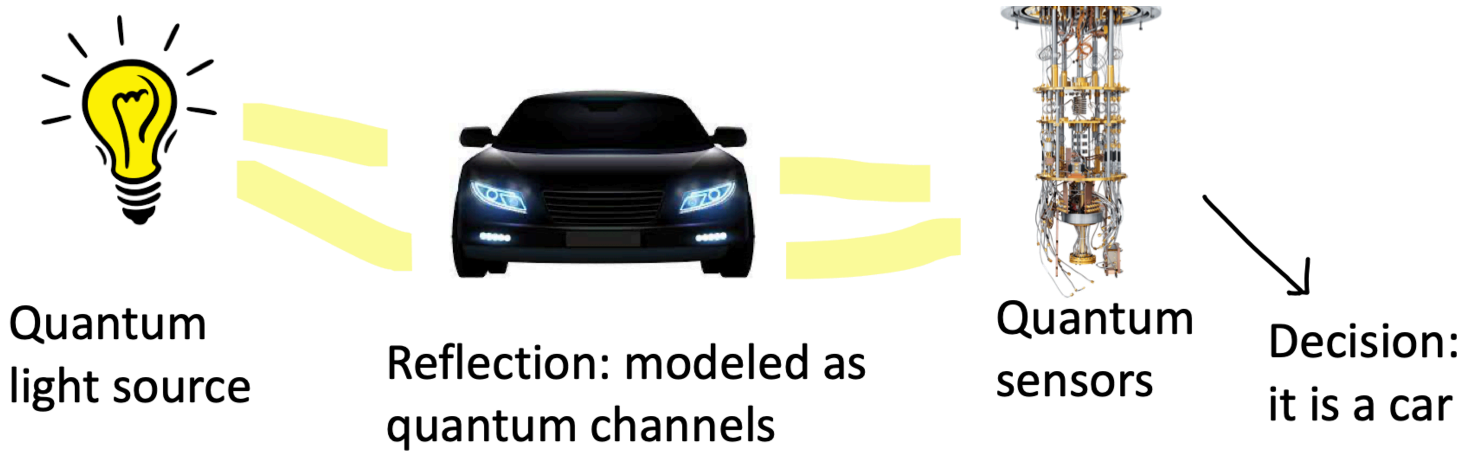


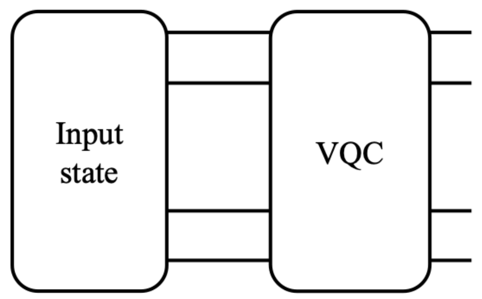
Quantum computers for data analysis & machine learning



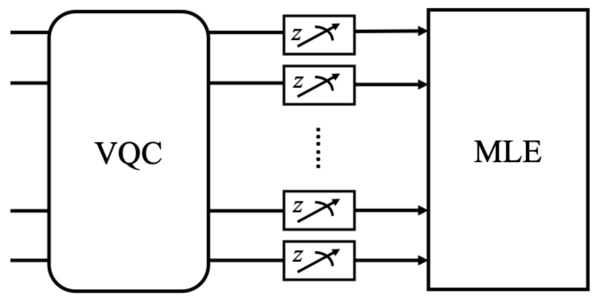
M. Schuld and F. Petruccione
Springer Press, 2018

“QQ” in action - courtesy of Q. Zhuang (U. of Arizona)





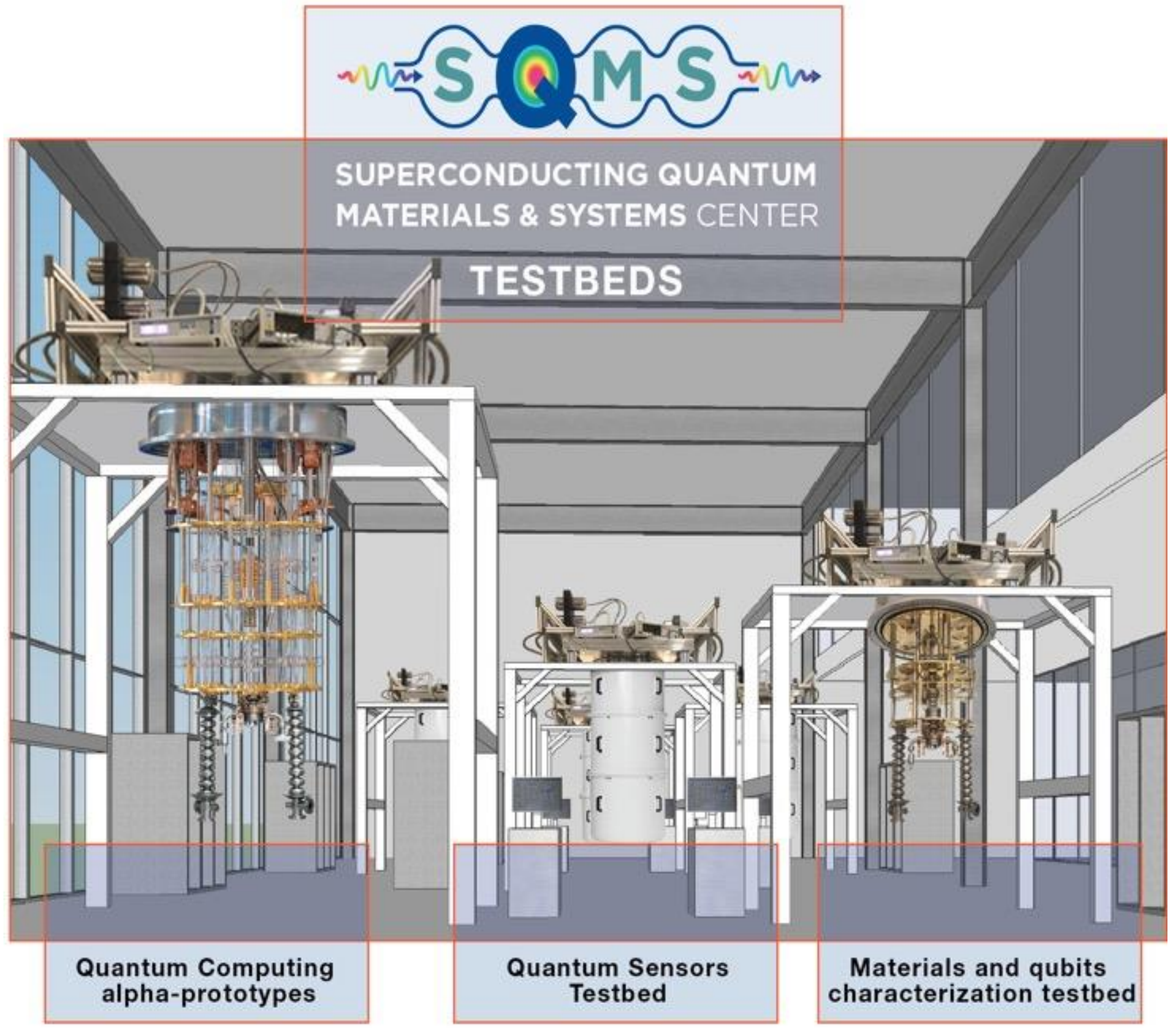
Quantum source
prepared by a VQC



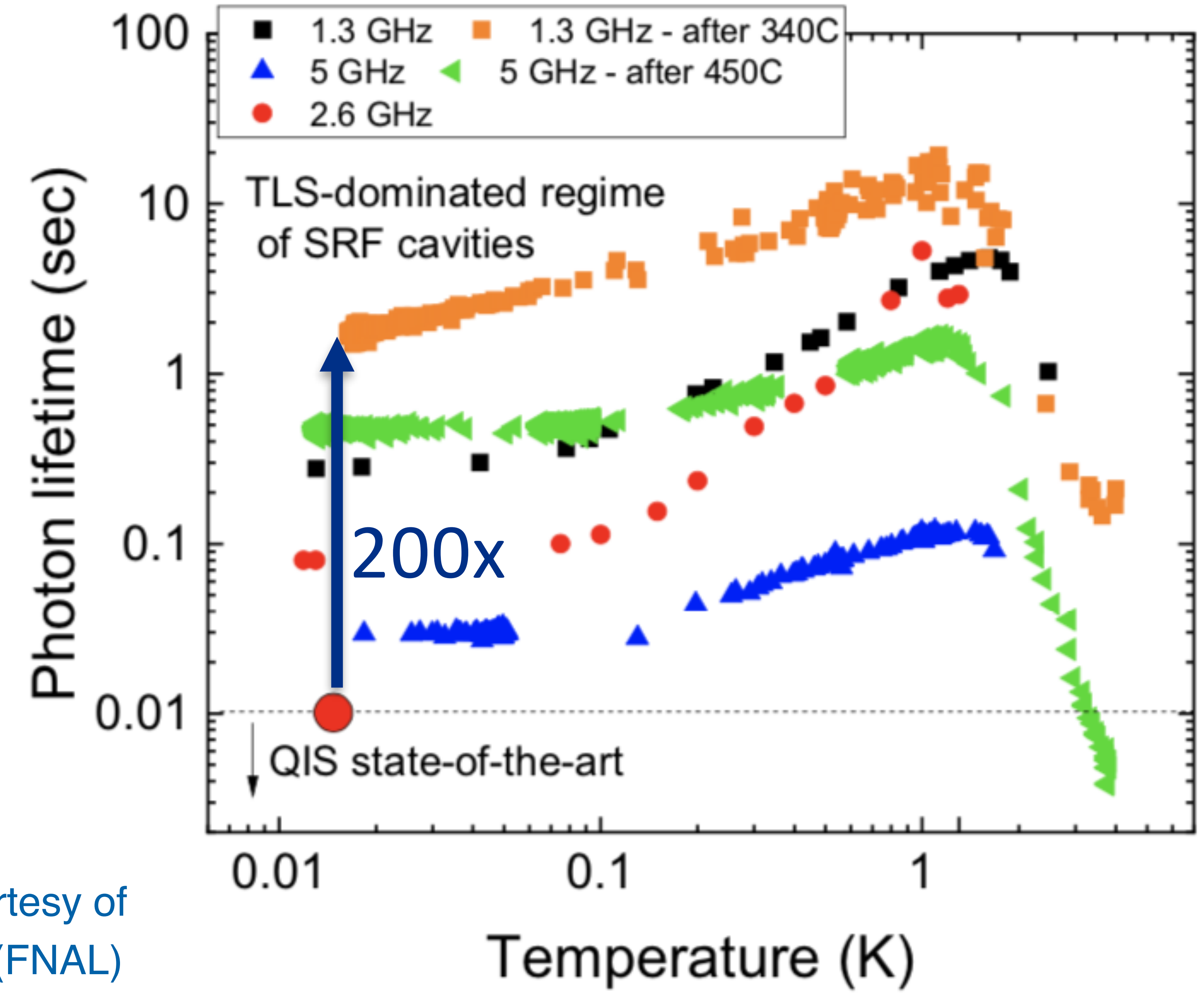
Measurement
performed by a VQC

- 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.

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.



A. Romanenko *et al*, Phys. Rev. Applied 13, 034032 (2020)

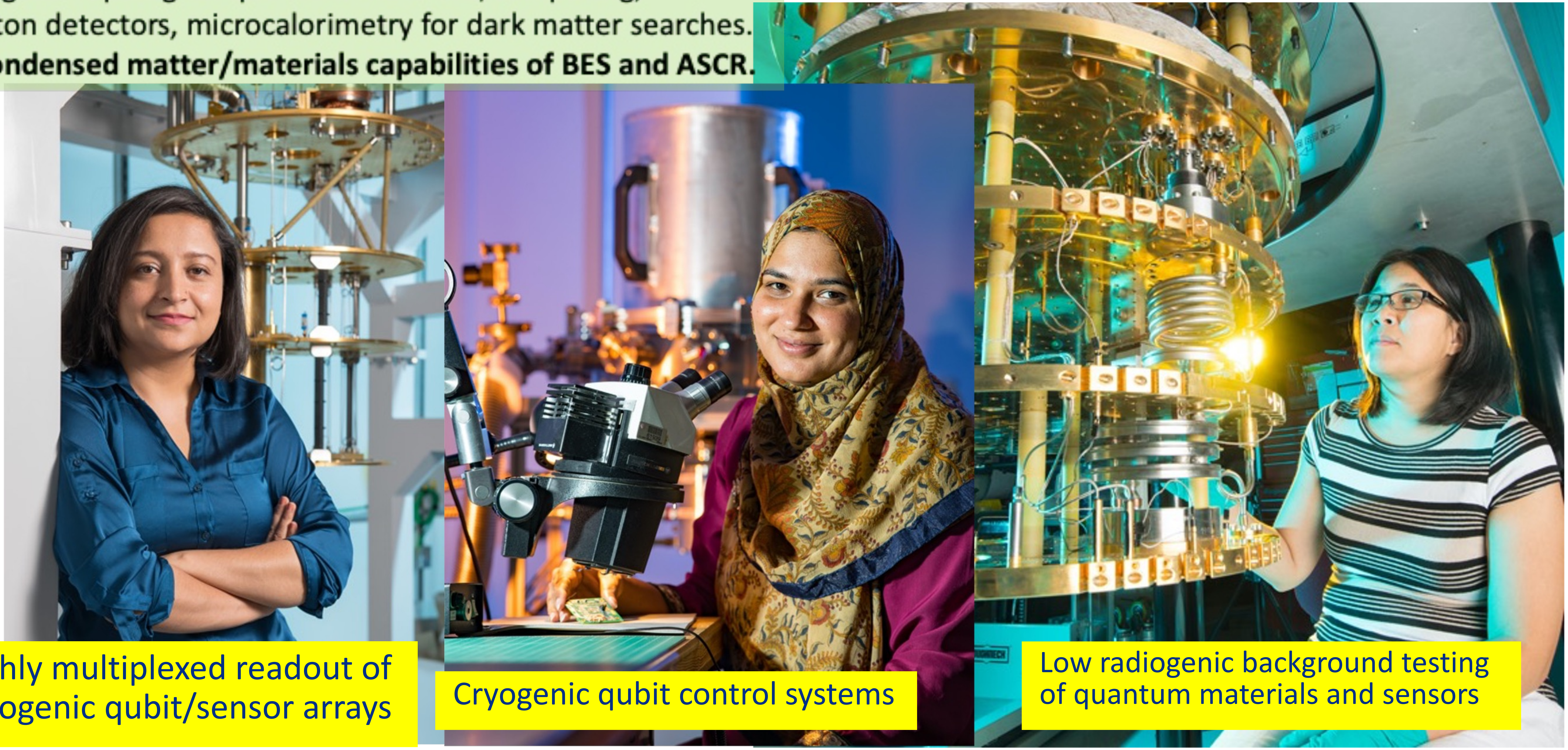
Slide material courtesy of Anna Grassellino (FNAL)

Fermilab

Slide material courtesy of
Panagiotis Spentzouris (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.



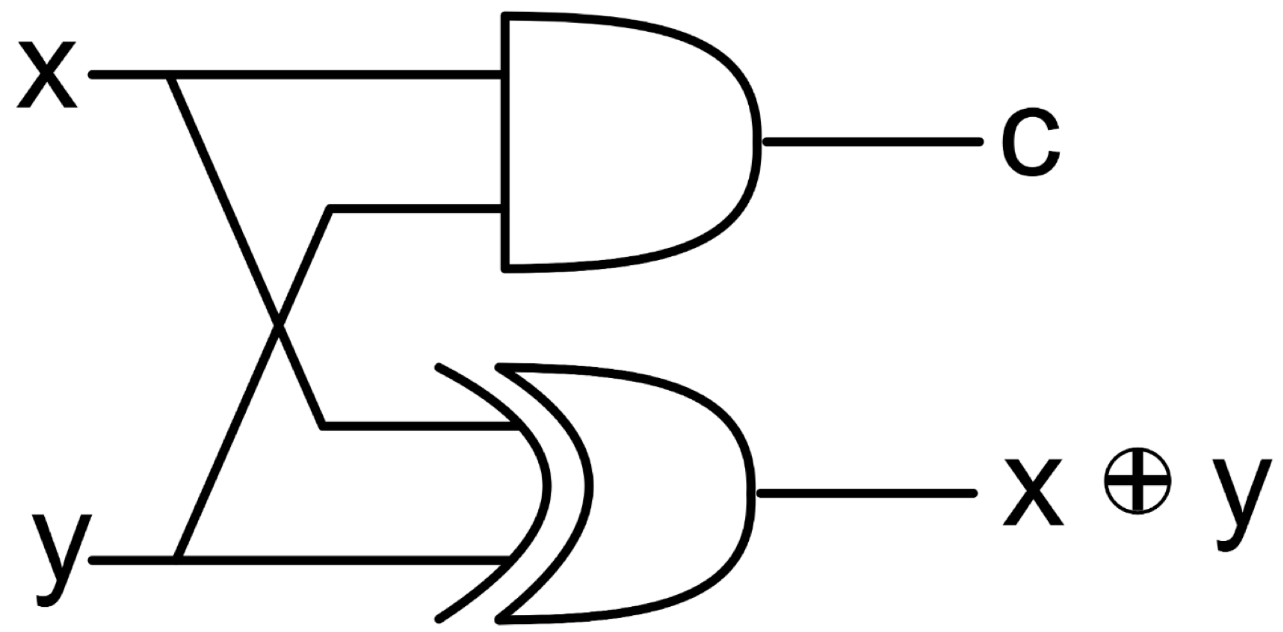
highly multiplexed readout of cryogenic qubit/sensor arrays

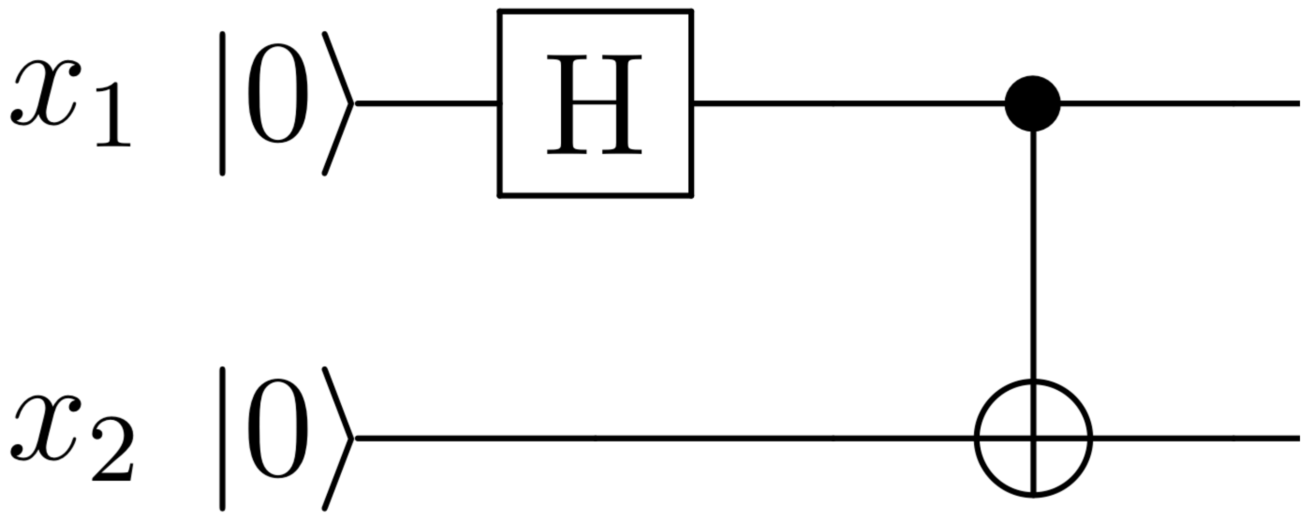
Cryogenic qubit control systems

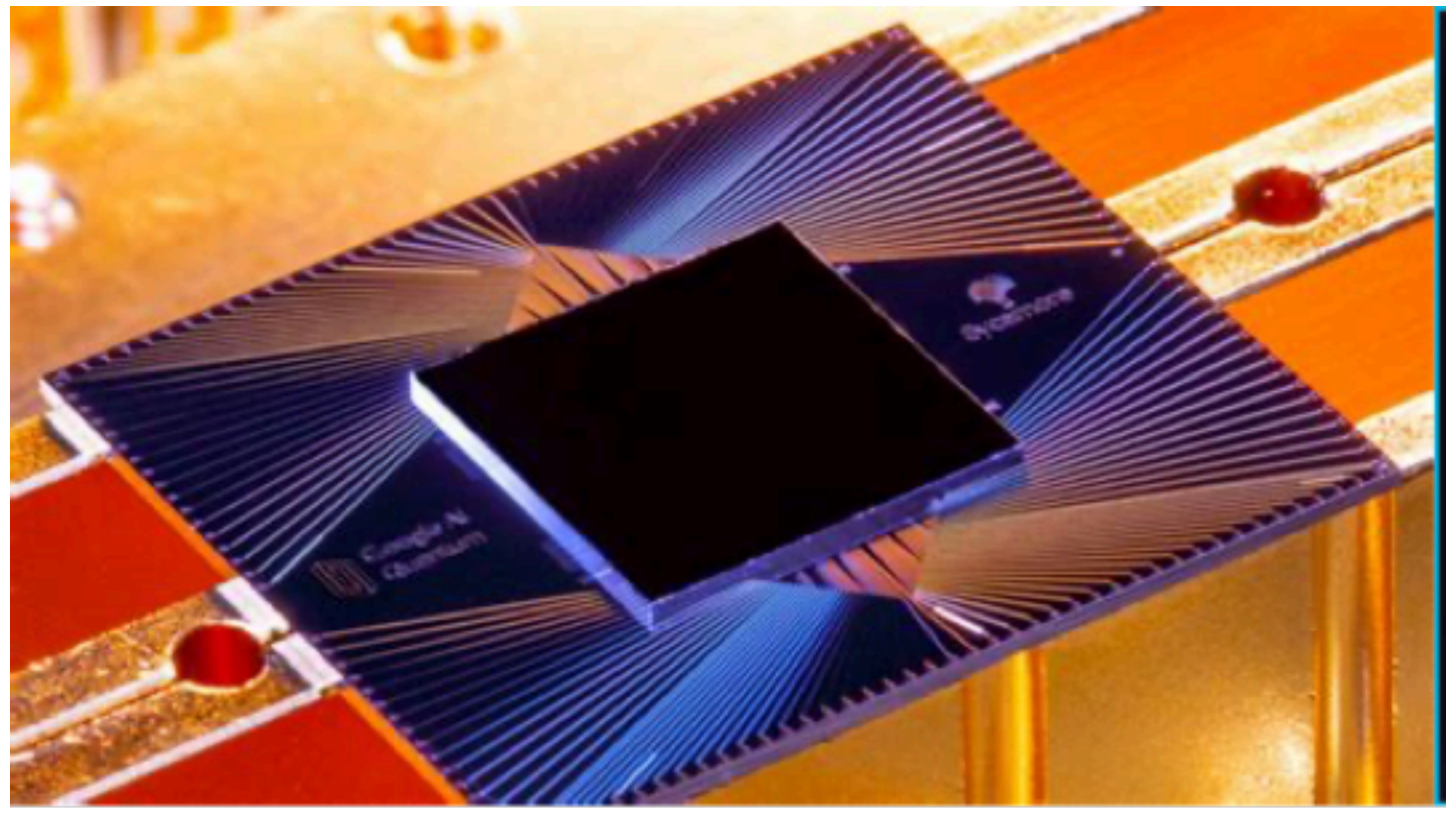
Low radiogenic background testing of quantum materials and sensors

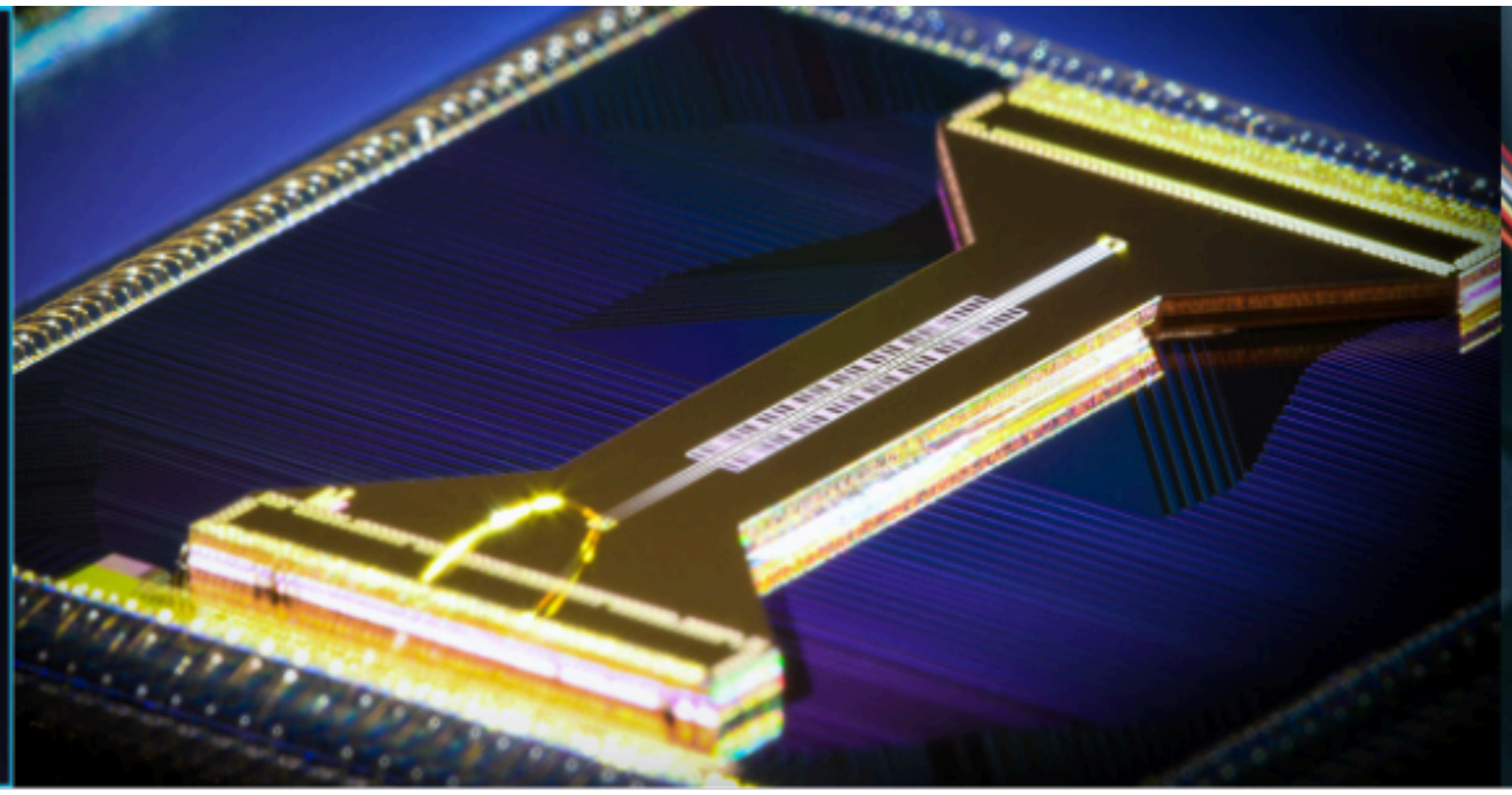
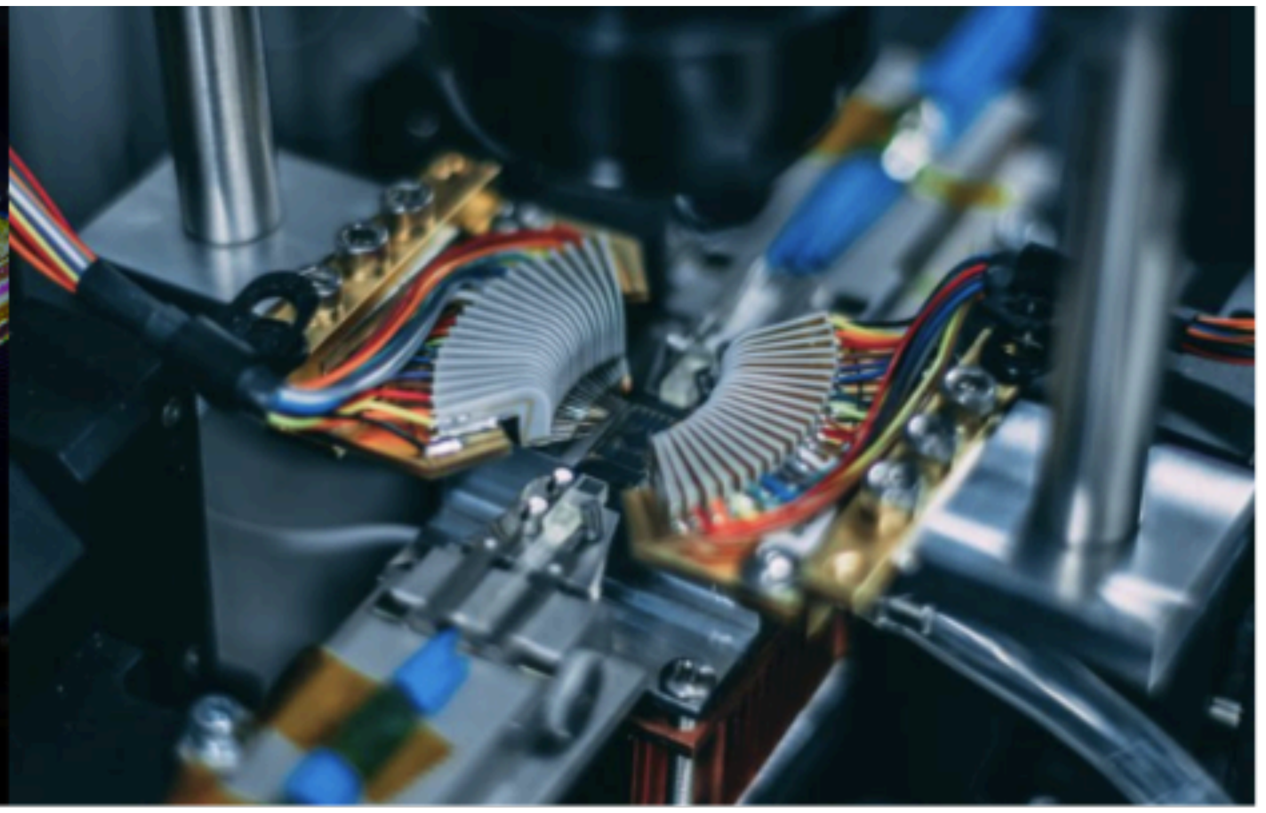
We are in early days…

- 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://ai.googleblog.com/2019/10/quantum-supremacy-using-programmable.html
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