Quantum Program = Working Group (my take)

- QIS is a new field for the lab and for DOE HEP. Still in the process of defining itself.
- A quantum science program, headed by Panagiotis and currently within the directorate has recently been formed.
- A group of involved lab scientist are meeting regularly (weekly-ish).
- The near and far term outlook is in flux. Being invented and negotiated in the lab and in frequent discussions b/w lab management and DOE.

- → the existing quantum group is also the working group for the retreat. The goal, unlike other groups, is to plan the program in the near term and introduce it to the lab.
- So far the group is mostly focused on grant proposals due in a week or so.

Quantum Science Program

Exploit quantum properties (coherence, superposition, entanglement, squeezing, …) for acquiring, communicating, and processing information beyond classical capabilities.

Application areas
- Sensing and metrology
- Communication
- Computing

With potential (or already demonstrated) impact in many areas of basic research

These areas have natural overlaps, e.g. sensors as qubits, quantum communication for sensing and metrology, transduction for communication, algorithms for quantum systems, QNN with sensors, …

Approach for early program

Goal: Produce high impact quantum science results in the near term, while building capacity for HEP needs in the long term

Engage with the DOE-SC QIS Initiative in ways appropriate to our role as the main HEP lab:

- Focus on the science
- Keep activities aligned to HEP program needs
- Leverage existing Fermilab expertise and infrastructure
- Engage partners who already have leading QIS expertise
- Act as a gateway and hub for the larger HEP community to engage with QIS

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Fermilab Quantum Science Program Thrusts

Superconducting Quantum Systems: Leverage Fermilab's world-leading expertise in **SRF cavities** to advance qubit coherence times, quantum memories, and scalability of superconducting quantum systems.

HEP Applications of Quantum Computing: Identify most promising **HEP applications** on near-term quantum computers; develop algorithms and experience with state-of-the-art machines and networks.

Quantum Sensors: Adapt and further develop quantum technologies (squeezing, entanglement,…) and techniques for state preparation and metrology, to enable new fundamental physics experiments.

- Time-binned photon quantum teleportation for communication
- Qubit-cavity systems for dark matter detection
- Cold atom interferometry (MAGIS-100)

Enabling technologies: **cold electronics, control systems, CCDs** for quantum imaging; access to quantum resources for community building and workforce development

Foundational Quantum Science connections to HEP: quantum field theory, black holes, wormholes, emergent space-time.

Towards the retreat

- Working on phase II of QuantISED (proposals due next week)
- Use this process to further define important activities both for the short and long term evolution of the program
- The next step will be to compose the narrative for the evolution of our activities in terms of grand challenges for the various technologies leading to advances in HEP science

Goal formulation (partial list)

- Quantum Simulation of Quantum Field Theory
  - Improve on existing hybrid methods to explore more of the dynamics of the theory under-study (utilizing ML and optimization techniques)
  - Develop error-hard, resource-light algorithms and approaches
- Deploy SRF-based technology experiments for dark-sector searches
- Deploy SRF-based technology systems for development of quantum communication and computing components and develop controls and algorithms for applications
- Complete demonstration of qubit-cavity systems for axion detection (including state preparation and metrology approaches for measurement) and deploy experiment
- Demonstrate entanglement distribution (successful R&D for detectors, electronics, controls, etc improvement)
- Demonstrate scalability of cold atom interferometers for dark sector and gravitational waves using Fermilab infrastructure, design next generation experiment for LBNF scales
- Develop machine learning and optimization approaches on NISQ to improve cosmology and LHC applications
- Develop controls systems with capabilities for driving “large-scale” (O(100) qubit) systems with error correction
- Develop cold-electronics to improve scalability and performance of sensor and computing systems