Quantum Information Science Enabled Discovery for High Energy Physics (QuantISED 2.0)

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Outline

- Other Resources
- Funding Opportunity Overview
- Technical Topics
  - HEP-QIS Theory
  - Quantum Sensing
  - Pathfinders
- General Guidance
- Frequently Asked Questions (so far…)
- Q&A

Other Resources for PIs

- Public Service Announcements
  - HEP Office Hours : next: Tue June 18 , 2pm ET.
    - Topic: How to Navigate the DOE Funding Process
    - See https://science.osti.gov/hep/officehours for more details
  - Webinars for targeted funding opportunities, see individual FOAs/lab calls below
- Other Funding Opportunities (not all currently open) that may be of interest
  - HEP Early Career Research Program now includes QIS topic area
  - RENEW and FAIR covering all HEP research areas, including QIS
  - Hardware-Aware AI/ML e.g., AI control of quantum systems
  - Microelectronics incl. extreme environments, e.g., cryogenic electronics
  - See also https://science.osti.gov/hep/Funding-Opportunities

HEP-QIS : QuantISED 2.0 DE-FOA-0003354

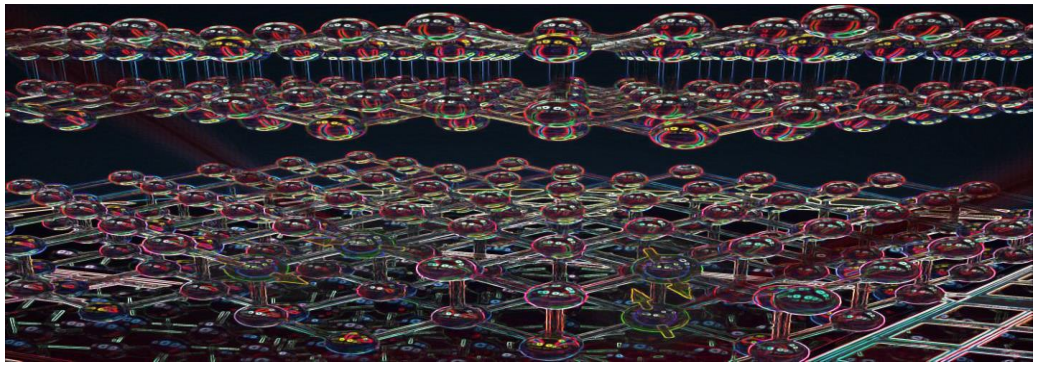
FOA Issued : May 7

Optional LOIs due: June 18

LOI response date: July 2

Full applications due: July 30

Webinar date : June 11



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https://science.osti.gov/hep/Research/Quantum-Information-Science-QIS

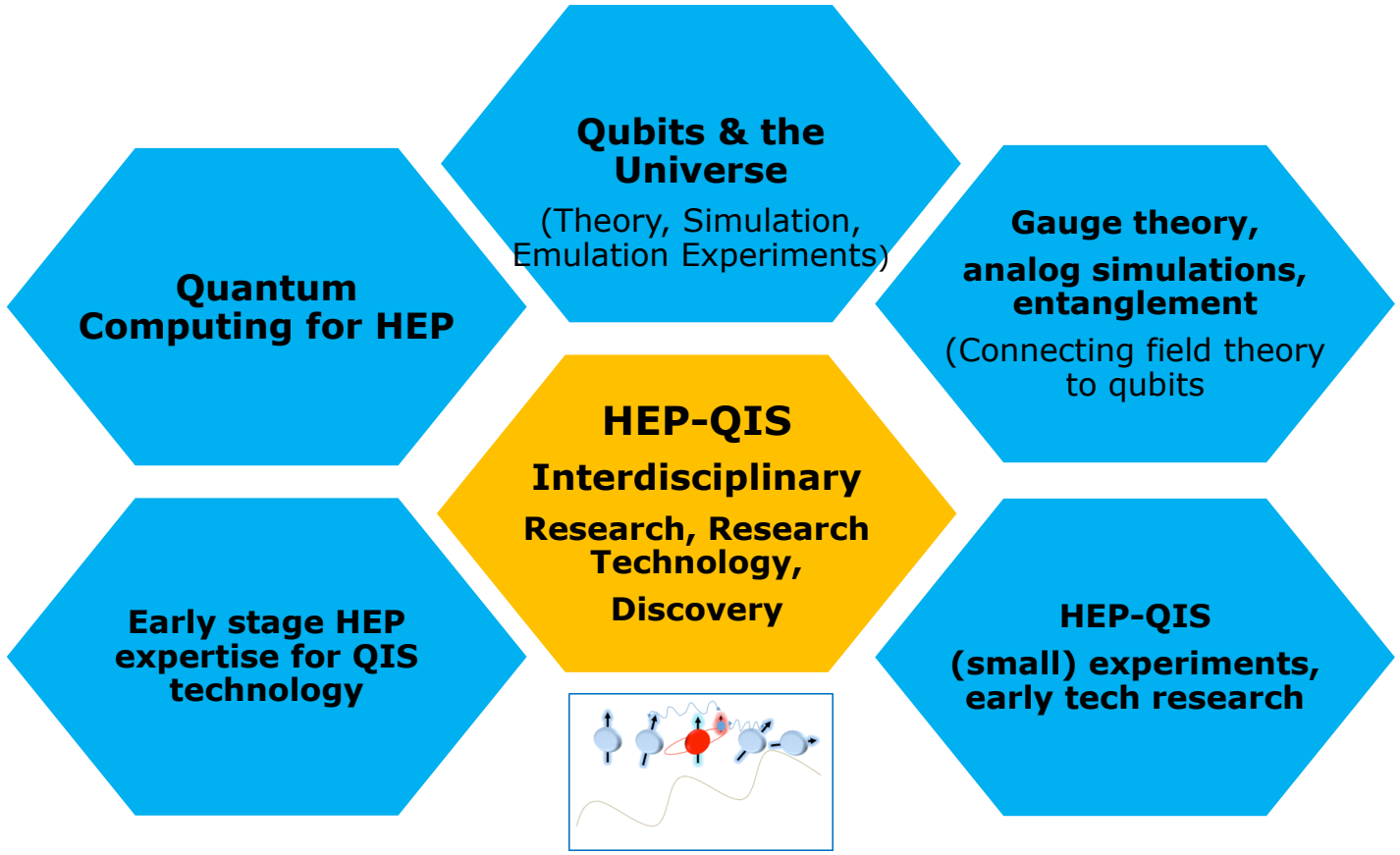
- Pursuing the exciting science opportunities in this emerging research area requires significant further development of the theory and practice of understanding and deploying real-world quantum systems, building on the achievements of the first cycle of QuantISED awards (2019-2020). Hence this call is QuantISED 2.0.
- Interviewed QIS PIs and consulted Snowmass QIS and Detector BRN/Sensor Workshop reports. This informs 3 main topical areas : HEP-QIS Theory; Quantum Sensing; and Pathfinder Experiments
- There are two application tracks that are differentiated by the award size, number of applicants and duration. See FOA for further guidance and restrictions.

Application Track	# of PIs	Award Floor (Total)	Award Ceiling (Total)	Award Duration
Seed Application	1	$140,000	$1,000,000	2-3 years
Team Application	>1	$1,200,000	$5,000,000	3-5 years

QIS for HEP ←→ HEP for QIS

- The HEP-QIS research program has been developed via a series of community round tables, pilot studies, and workshops since 2014; see https://science.osti.gov/hep/Community-Resources/Reports; and https://arxiv.org/abs/2311.01930 and references therein
- HEP-QIS supports basic research in:
  - HEP-related foundational quantum theory and quantum simulations
  - QIS-enabled quantum sensors enabling novel experiments to explore new HEP physics
  - HEP-developed theoretical and experimental techniques/technologies for QIS
- HEP issued Funding Opportunity Announcements "Quantum Information Science Enabled Discovery (QuantISED)" in FY 2018 and FY 2019; awards Abstracts can be found here

QuantISED 1.0 : HEP-QIS Programmatic Thrusts (2018)



Where We're Going with the HEP QIS program

- Develop a HEP QIS Core program with room for directed R&D and special projects; distinct from but synergistic with QIS Centers
- In the Core program, predictable multi-year funding but with the flexibility to respond to new research developments; open-ended
  - Part of annual HEP Comparative Review process (not there yet)
- In the Directed program, more formal milestones and "deliverables"; cross-cutting efforts; traineeship opportunities; time-bound
  - Special-purpose FOAs and lab calls (QuantISED 2.0)
- Thereby develop career paths for students, postdocs, junior faculty working in this area
  - Include QIS track in HEP Early Career

Science Vision Statement

- Cross-cutting the traditional frontiers and thrusts of the HEP program, the QIS subprogram exploits the interdisciplinary nature of QIS and associated partnerships for exploratory, early-stage research aimed at high impact discoveries aligned with HEP science goals, but also driving developments in foundational QIS and related scientific and technology research areas.
- The main topics to be investigated are:
  - research in QIS theory and quantum sensing that extends the scientific reach of existing HEP programs well beyond what is currently achievable and enables new lines of inquiry;
  - using quantum theory to improve the understanding of capabilities and limitations of fundamental QIS; and
  - developing pathfinding experiments that demonstrate the full potential of state-of-the-art quantum sensing as a powerful tool to enable new discoveries when scaled from proof of concept to essential scientific instrumentation

QuantISED-2.0 Theory

- We look to continue and build upon aspects of the existing QuantISED program:
  - Applications of Quantum Information Theory and Entanglement in Quantum Field Theory and Quantum Gravity.
    - Theoretical Research exploiting developments in quantum gravity, computational complexity, the AdS/CFT correspondence, quantum information theory, emergence of space-time, quantum error correction, black hole physics, scrambling, and qubit system thermalization
    - Theoretical investigations that could lead to experiments using quantum devices (i.e., exploiting superposition, entanglement, squeezing, …) to measure fundamental parameters or test theoretical frameworks.
  - Quantum Computing for HEP
    - Reformulating problems in HEP theory, like lattice QFT, so that they can be addressed with quantum computers.
    - Quantum field theory algorithms and simulations including quantum chromodynamics and electrodynamics, accelerator modeling codes, and computational cosmology relevant to HEP
  - Theoretical support for new experimental probes of fundamental physics involving QIS-based Quantum Sensors.
    - Theoretical investigations (model building, calculations of possible signals) of measurements that can be made with quantum devices.
    - Theoretical support for the development of quantum sensors.

QuantISED-2.0 Theory Continued

- We are also interested in expanding the scope of QuantISED, opening new areas of HEP theory to Quantum Information Science.
  - Foundational field theory techniques, gauge symmetries, and tensor networks invoking quantum information and entanglement concepts that advance knowledge including description of scattering, bound state problems, and advanced gauge theories.
  - Further developments, expanding the application of quantum computing to open questions in High Energy Physics.
- We do not support QIS research without an HEP theory overlap
  - No Quantum Information Theory without application to or adaptation from HEP theory.
  - No general algorithmic development for quantum computing.

QuantISED-2.0 Quantum Sensing for HEP

- Quantum techniques and technologies prepare, control, and interrogate individual quantum states and may make use of quantum mechanical phenomena like superposition, entanglement, squeezing, and backaction evasion
- Quantum sensors with their appropriate measurement protocols can exploit these quantum phenomena to make measurements with a precision better than the Standard Quantum Limit, with the ultimate goal of reaching the Heisenberg Limit
- The full impact of quantum sensors on HEP science will only be reached as full Quantum systems are implemented, taking advantage of quantum correlations across arrays of sensors by linking them to each other with quantum mechanical means

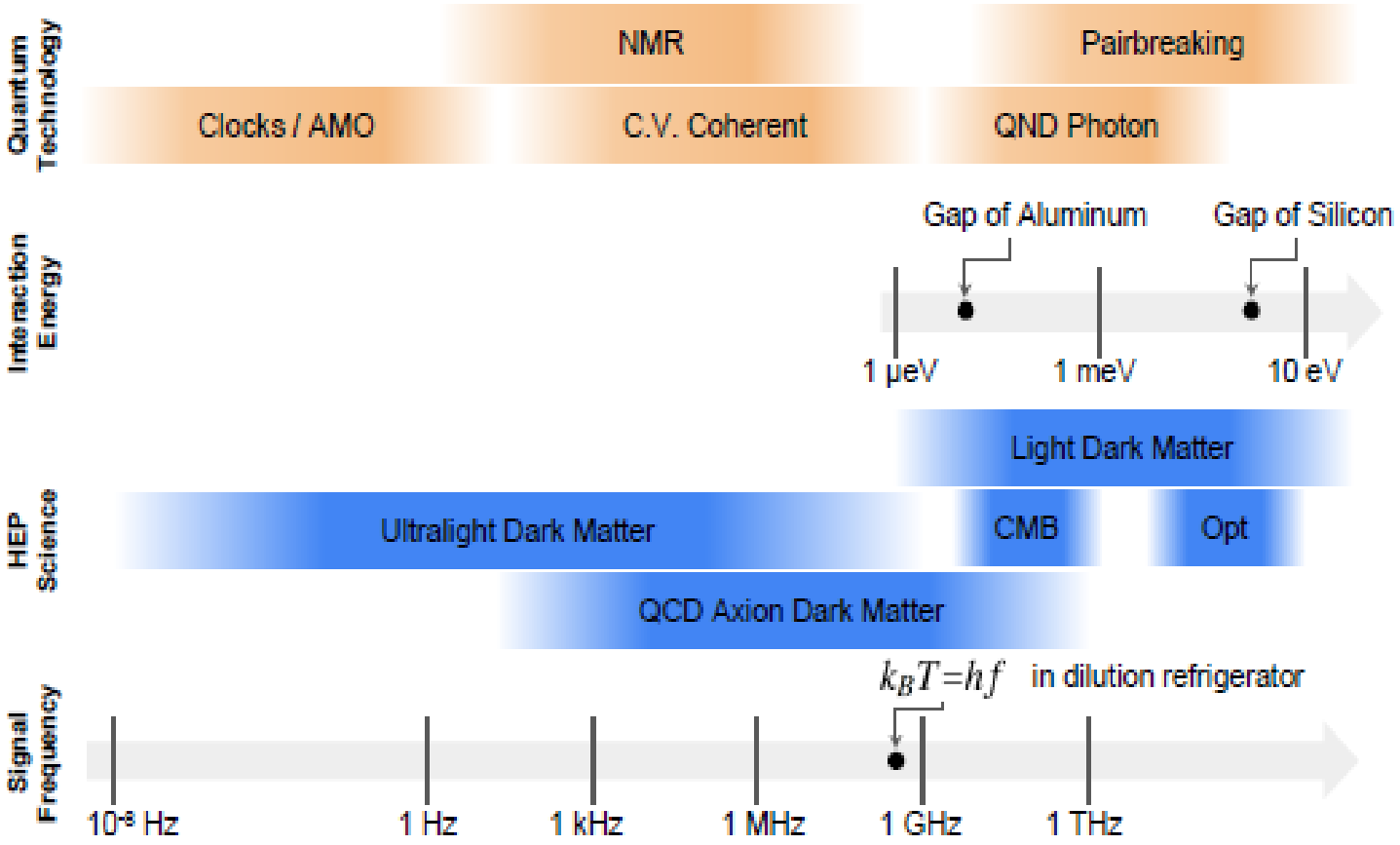
QuantISED-2.0 Quantum Sensing for HEP, Continued

- **Quantum sensors:** any device whose measurement capabilities are enabled by our ability to prepare, control, and interrogate its quantum states
- **Quantum sensors** include
  - qubits and continuous-variables quantum devices of various types as developed by the quantum computing community;
  - quantum materials and spin ensembles as developed by the condensed matter and materials science community;
  - atomic and optomechanical sensors, clocks, and interferometers as developed by the AMO and gravitational wave communities

🡸 in each case re-purposed and re-optimized to target HEP science

Example: Quantum Sensing for Dark Matter Searches

- Searching for (ultra) low-mass dark matter particles over a huge mass range employing a multitude of technologies
- Clocks / AMO (clocks, ion traps, neutral atoms interferometers); nuclear magnetic resonance (NMR) with spin ensembles; Continuous Variable (C.V.) Coherent (including parametric amplifiers, radio-frequency quantum upconverters); Quantum Non-Demolition (QND) photon sensors (including qubits, Rydberg atoms); and Superconducting Pairbreaking detectors (including superconducting transition-edge sensors (TES), microwave kinetic inductance detectors (MKIDs), superconducting nanowire single photon detectors (SNSPDs))



QuantISED 2.0 Pathfinders

- **Pathfinders** are innovative experimental concepts that employ quantum sensors, superconducting devices or other quantum systems, to enable proof-of-principle measurements of fundamental properties of particles and forces consistent with the HEP mission and the strategic priorities of the field.
- These "pathfinder" applications should demonstrate the potential to significantly extend the discovery reach in a particular area of experimental HEP beyond what is presently achievable, but do not necessarily have to produce physics results during the award period.
- Applications may include theoretical studies, simulations, and device prototypes necessary to achieve the proof-of-principle demonstration. Team applications that leverage existing research group capabilities and/or DOE lab facilities are particularly encouraged.

QuantISED 2.0 Pathfinders, Continued

- **Note** this definition of Pathfinders does not exclude "Quantum 1.0" setups. This is different than the focus of Quantum Sensing topic described above.
- Specifically, Pathfinders that propose to "do nothing" Quantum 2.0 (e.g., entangled sensor arrays, squeezed states, etc.), but instead deploy better superconducting sensors, readout, clocks, cavities, etc., are allowed; BUT they should have a clear pathway to evading the Standard Quantum Limit, which may be beyond the proposed scope of the Pathfinder phase.
- Bottom-line: successful Pathfinder proposals need to deploy something in the 3-5 year timeframe of the proposal, which means they have very limited time for any further R&D on sensors etc.
- On the other hand, we also want something that is forward-looking in terms of physics goals and/or technology goals. Higher risk/reward is preferred over important but incremental advances in "established" technologies.
- PIs have to figure out how to balance these two goals in a compelling way.

QuantISED 2.0 Parameters (see also FOA for specifics)

- **Eligibility**: Open to all institutions/individuals except certain non-profits.
  - Institutions and individuals underrepresented in the HEP research portfolio are particularly encouraged to apply.
- **Limitations:** No more than 2 LOIs and 2 full applications per PI. This includes being a co-I on a Team application from your institution or another institution.
  - No limitation on # of applications/LOIs per institution.
- **Lab/Univ restrictions:**
  - Universities may be lead or partner institutions on any proposal
  - DOE Labs may be lead on Team proposals, and subwardees on Seed proposals
  - Other non-DOE FFRDCs may be subawardees only
- **New/Renewal Proposals:** Renewals accepted only for Team proposals
  - For technical reasons, DOE Labs can only submit New proposals to this FOA
  - In practice, a New application can continue activities started under a previous award (eg QuantISED 1.0). See FOA for additional reporting requirements.

Disclaimers

- Applications dedicated to these items are nonresponsive and may be declined without merit review:
  - General quantum computing research, algorithms, networks or computing hardware;
  - Basic research within the mission space of other SC programs, such as quantum materials;
  - Research and/or technology R&D funded by other HEP sub-programs or any other research scope that is duplicative of active awards; and
  - Other research that is outside the scope of the HEP mission, even if it uses QIS tools and techniques
- Note the QuantISED 2.0 program does not support research on quantum computing *per se*; but applications may leverage calculations performed on currently available qubit systems, quantum annealers or other quantum test beds that are available at their institution(s) or supplied from partners.
- Quantum machine learning is considered part of quantum computing for this FOA.

Backup

HEP Research Activities Supported

✓What DOE supports

- Efforts that are in direct support of our programs
  - Support depends on merit review process, programmatic factors, and available funds
- Research efforts (mainly scientists) on R&D, experiment design, fabrication, data-taking, analysis-related activities
- Some engineering support may be provided in the Technology R&D subprograms
- Theory, simulations, phenomenology, computational studies

- **Faculty support**
  - Based on merit reviews and/or optimizing the number of research personnel supported by financial assistance awards, support of up to 2-months faculty summer salary
  - Summer support should be adjusted according to % time the faculty is on research effort
- **Research Scientists**
  - Support may be provided, but due to long-term expectations, need to consider case-by-case on merits: whether the roles and responsibilities are well-matched with individual capabilities and cannot be fulfilled by a term position
  - Efforts are related towards research; not long-term operations and/or project activities

Programmatic Considerations

- Many factors weigh into final funding decisions
  - ***Compelling research proposal*** for next ~3-5 years
    - ✓ **Interesting? Novel? Significant? Plausibly achievable?**
    - ✗ **Incremental? Implausibly ambitious? Poorly presented?**
  - ***Significant recent contributions*** in recent years
    - Synergy and collaboration within group and with others (as appropriate)
    - Contributions to the research infrastructure of experiments or local group
  - ***Alignment with HEP*** programmatic priorities
  - ***Balanced program*** of R&D/design/physics studies, support of construction or operations, data analysis (as appropriate)
  - ***Training and mentoring of junior researchers***
  - ***Opportunity to support new (and new to DOE) investigators***
  - ***Promoting diversity of investigators and institutions, particularly those currently underrepresented in the HEP portfolio***