Looking Ahead

Cross-fertilization between QIS and NP offers exciting opportunities for discovering new platforms, protocols, and approaches that can accelerate the advance of quantum technology. A multi-disciplinary quantum roadmap would help address the fundamental science challenges within NP, highlighted in the 2015 *Nuclear Physics Research Opportunities and Priorities Long Range Plan "Reaching for the Horizon"*.

Our report presents a **vision for accelerating that development** by

- forming consortia in quantum simulation and quantum sensing;
- collaboration with other domain sciences;
- growing a quantum-ready NP work force pipeline of scientists, engineers and developers who have viable career paths;
- small- and modest-scale, high-reward-potential explorations;
- embracing inclusive, diverse ways of thinking, learning, engagement, and research;
- building upon NP's community organization to address challenges.

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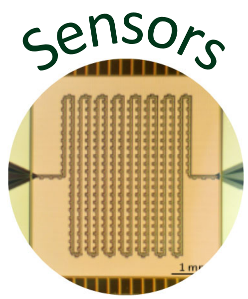

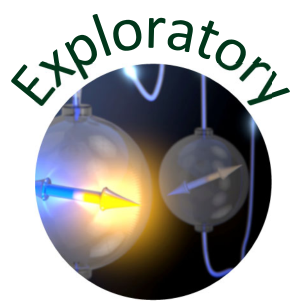

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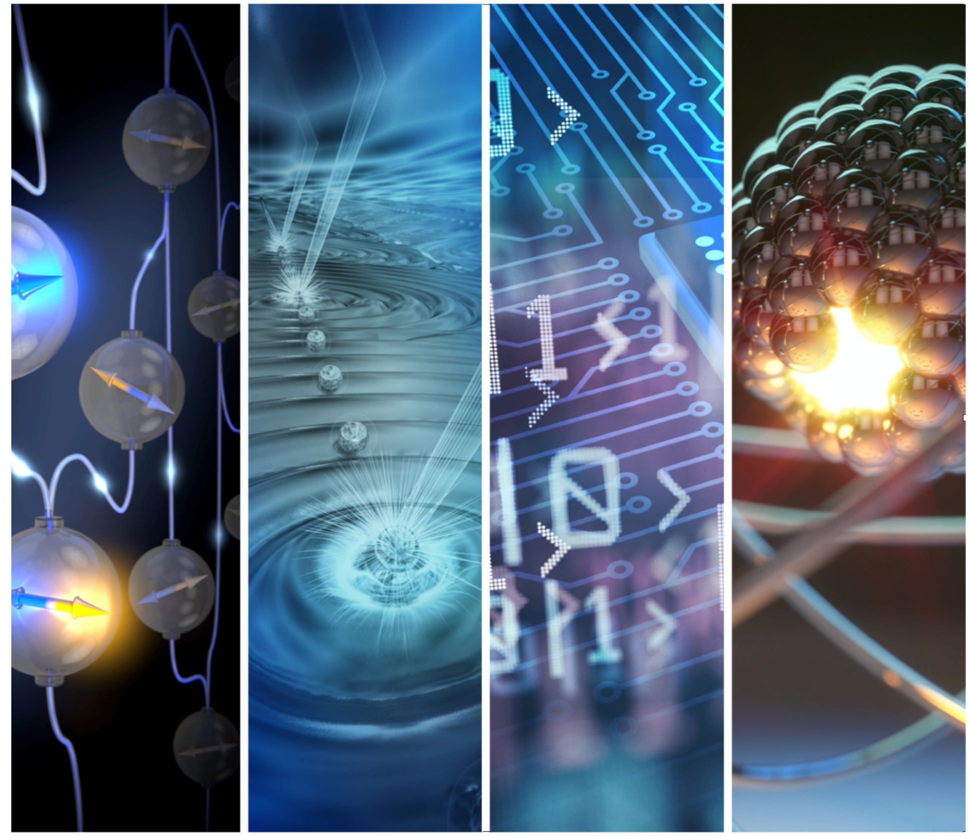

Nuclear Physics and Quantum Information Science

Report by the NSAC QIS Subcommittee *(October 2019)*

"Nuclear Physics research will advance, and be advanced by, quantum information science in numerous and unique ways."

Introduction

Nuclear Physics (NP) research will advance, and be advanced by, quantum information science (QIS) in numerous and unique ways. QIS is poised to bring about significant and perhaps disruptive changes in science, technology, national security, and societal infrastructure. It harnesses the fundamental properties of quantum mechanics to build computers, communications systems and sensors in new ways.

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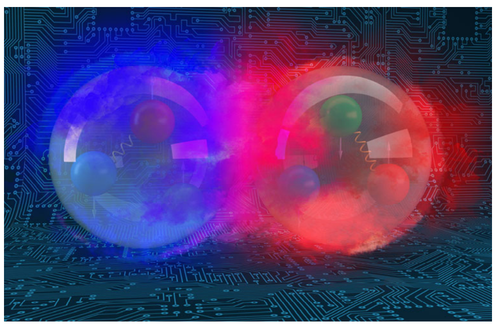

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Establishing a **national quantum ecosystem** to accelerate advances in QIS is reliant on advances in the domain sciences, and **NP has a natural and unique role** in this ecosystem:

- NP grand challenge problems through quantum simulation
- Techniques in quantum many-body systems
- Techniques and quantum sensors in the NP experimental program
- NP contributions complementing other domains

Expanding activities at the NP-QIS interface and **integrating them into the national effort** will benefit both NP and QIS.

NSAC Subcommittee: Front (L-R) A. Poon (LBNL), J. Formaggio (MIT), S. Quaglioni (LLNL), A. Boehnlein (JLab), J. Preskill (Caltech), C. Muschik (Waterloo), M. Savage (Chair, INT and UWash); Rear (L-R) K. Rajagopal (MIT), D. Beck (Illinois), D. Hertzog (NSAC Chair, UWash), J. Carlson (LANL), D. Dean (ORNL), M. Dietrich (Co-chair, ANL), M. Greiner (Harvard), W. Fairbank, Jr. (Colorado State), J. Nico (NIST). Photograph by M. Shinn, DOE.

The NP-QIS Interface

Enhanced sensitivity
Sensors using coherence
and entanglement

QIS and quantum computing have the potential to disruptively accelerate areas of NP research. Quantum sensors will play a key role:

- Improve capabilities through evolution of Quantum 1.0 technologies
- Develop Quantum 2.0 technologies, utilizing entanglement and coherence, for NP research

Improved sensitivity to heat and light will enhance searches for rare subatomic processes probing fundamental aspects of our universe, e.g., neutrinoless double beta decay of nuclei would reveal lepton number violation.

Simulation for finite density
real-time evolution

Quantum computing holds the promise of solving key problems in NP, particularly those involving fundamental symmetries and dynamics:

- The Big Bang and early universe phase transitions
- Supernovae and extreme astrophysical environments
- Low-energy nuclear reactions and nuclear forces
- The formation of protons, neutrons and nuclei
- High-energy nuclear collisions, highly inelastic neutrino-nucleus collisions
- Response of nuclei to probes, e.g., Dark Matter and high-energy electrons

Radio– and isotopically–
pure materials
Large cryogenic systems

NP techniques, technology and expertise will advance QIS:

- Design of future qubits for computing and sensing will benefit from
  - the US Isotope Program;
  - NP expertise in shielding against cosmic rays, fabrication of radio-pure materials, and large cryogenic systems;
  - unique NP research focused on strongly correlated systems;
  - techniques developed in NP and HEP for lattice QCD.
- NP theoretical techniques for the design of future quantum computers
- Nuclear clocks could be orders of magnitude more precise than atomic clocks