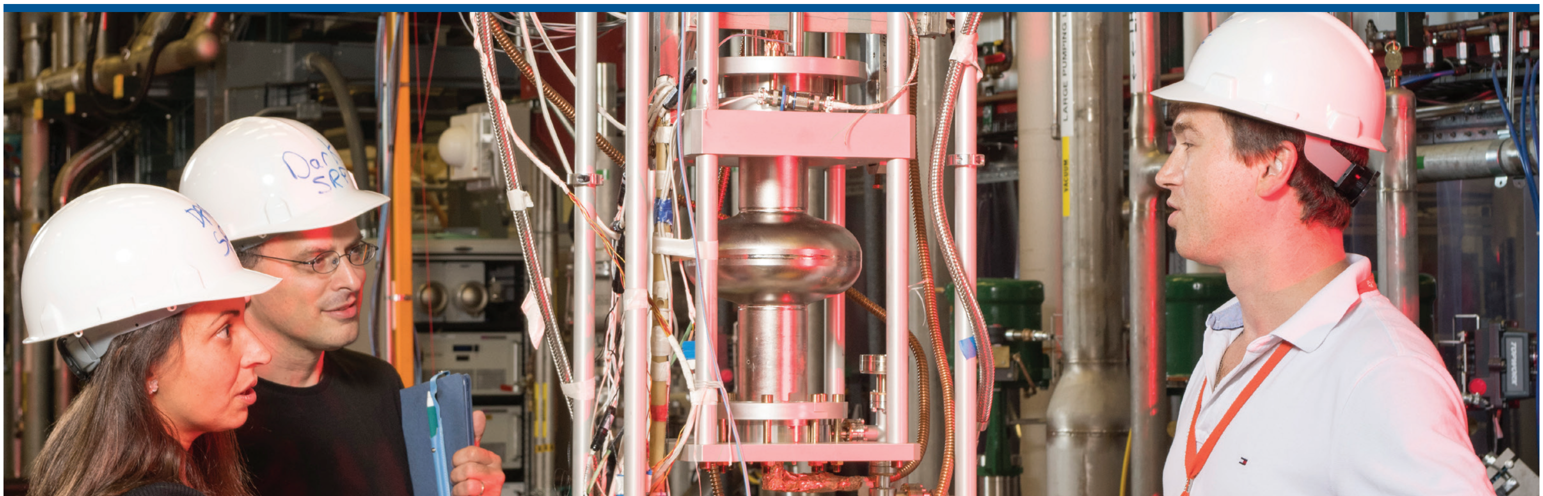
Quantum science and technology

Fermilab's leading-edge quantum science program builds on the lab's unique capabilities as both the U.S. center for high-energy physics and a leader in quantum physics research.



Fermilab researchers are advancing superconducting technologies for quantum computing.

Quantum science and technology have the potential to revolutionize particle physics. Fermilab researchers take advantage of the quantum properties of physical systems to acquire, communicate and process information far beyond what we can accomplish with classical capabilities. Successful quantum applications could be transformational for particle physics, enabling studies of nature's fundamental properties that would not otherwise be possible.

Home to national quantum research center

Fermilab is the home of the Superconducting Quantum Materials and Systems Center, one of only five National Quantum Information Science Research Centers in the United States. At SQMS, researchers from more than 20 laboratories, academic institutions and companies are working together to advance superconducting quantum devices. Their ambitious aim is to build a revolutionary quantum computer. They are also developing quantum sensors for the discovery of new particles, an effort that will have an impact in scientific fields beyond physics.

Fermilab also plays a key role in a second national center led by Oak Ridge National Laboratory called the Quantum Science Center. At QSC, Fermilab scientists contribute their particle physics expertise to developing novel quantum technologies targeting advances in quantum materials and dark matter science.

Quantum computing technology

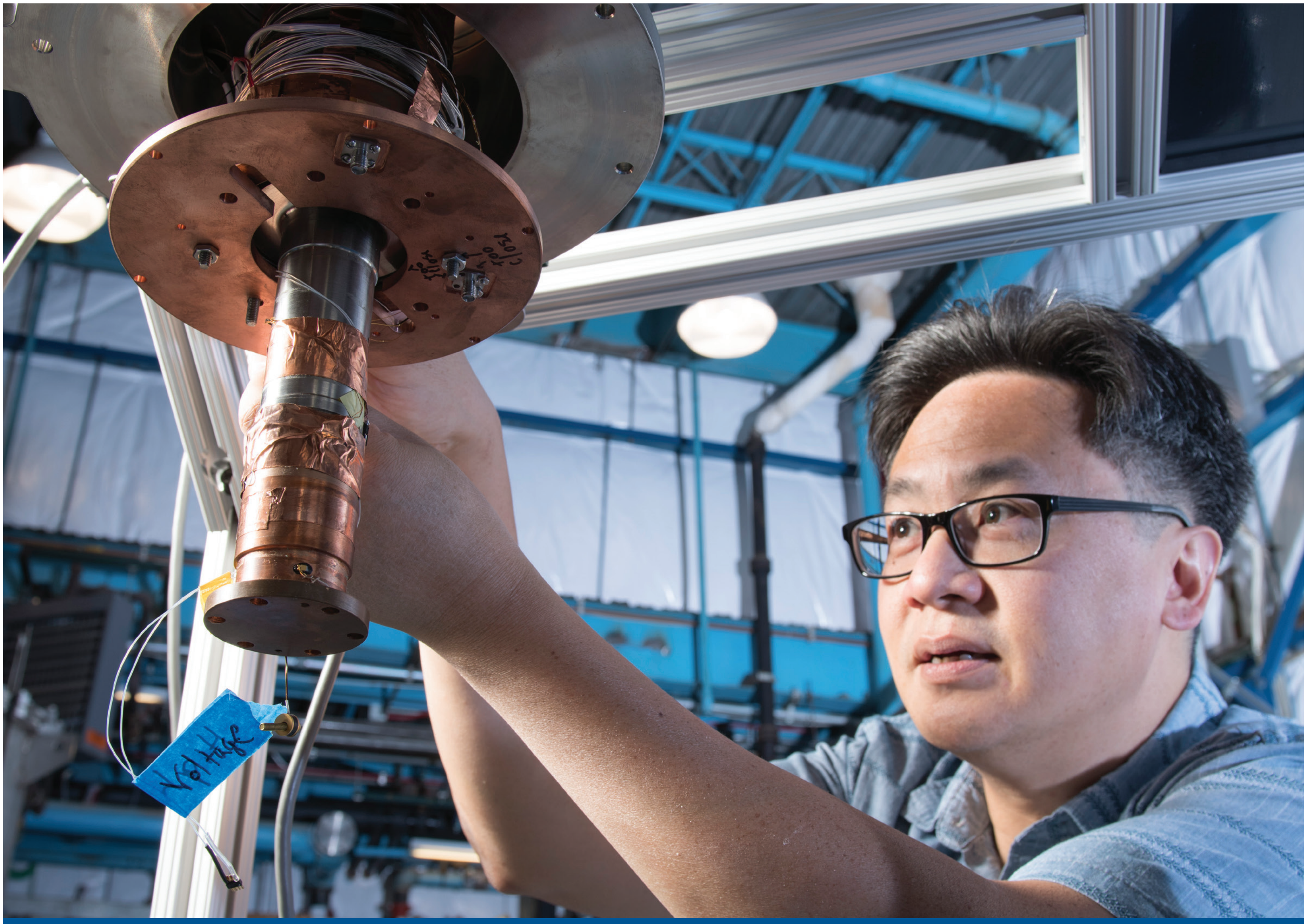
One of the biggest barriers to building a viable quantum computer relates to the amount of time that quantum bits, or qubits, can maintain information. Fermilab scientists and engineers are extending this coherence time by leveraging a core technology used to advance particle accelerators: ultraefficient, superconducting resonators. They're developing these resonators to stretch a qubit's coherence time by orders of magnitude. The resonators can also be used to vastly improve the reach of experiments searching for dark photons, hypothetical particles related to dark matter.

Researchers are also designing novel electronics, controls and readout optimized to work with a variety of quantum systems, including those developed for the Fermilab quantum science program. The electronics aim to address unique challenges, such as operating at extremely low temperatures.

Quantum communication

Experts have devised a way to use a phenomenon called quantum entanglement to send information over long distances, and high-fidelity quantum teleportation has been achieved at the Fermilab Quantum Network (FQNET), an optical-fiber-based local quantum network connecting remote nodes within Fermilab. FQNET uses commercial optical fibers to distribute quantum information across various distances. Caltech spearheaded and leads this project, and the development of state-of-the-art devices needed for the network is carried out at Caltech and, through Caltech, at NASA Jet Propulsion Laboratory.

Fermilab and its partners are also expanding FQNET's point-to-point communications system into a multinode, multiuser network that will crisscross Chicagoland: the Illinois-Express Quantum Network, or IEQNET. At IEQNET, researchers will develop and demonstrate the operation of repeaterless transparent optical quantum network designs.



Scientists at Fermilab are using quantum technologies to look for direct evidence of dark matter.

Quantum computing applications

Strengthened by the advantages of quantum computing, machine learning can be used to explore rich sets of connections in particle physics and astrophysics when it comes to pattern matching and classification. Quantum-based machine learning is expected to make it easier to separate stars from galaxies in sky surveys and help optimize the modeling of high-energy particle collisions. In a Caltech-led initiative, Fermilab physicists are also classifying subatomic particle interactions and reconstructing particle trajectories in detectors.

Quantum simulations will also be extraordinarily valuable for particle physics theory. Integrating these simulations into existing computing infrastructures will make complex and difficult calculations easier and faster. A lab program to develop such quantum algorithms will open avenues to problems that are out of reach for classical computers.

Quantum computing is being used in neutrino physics, one of the lab's core pursuits. As part of an initiative led by Los Alamos National Laboratory, Fermilab scientists are investigating how quantum computing could help simulate the detailed outcomes of interactions between neutrinos and complex, heavy nuclei.

Quantum sensors

Superconducting qubits, developed for quantum computing, may be the key to detecting the axion, a candidate particle for the mysterious dark matter that makes up a quarter of the universe. A Fermilab team is developing an ultrasensitive, qubit-based detector that will improve experiments' searches for the elusive particle.

Also under development is a next-generation version of the charge-coupled device, or CCD. This skipper CCD, designed to image objects one light particle at a time, will produce pictures with exceptional resolution for quantum imaging experiments. The lab is also exploring the quantum entanglement of photons as a tool to look for dark photons.

Fermilab is the host lab for MAGIS-100, a Stanford University-led initiative. The aim is to perform precision quantum measurements to look for lightweight dark matter particles and establish a high-sensitivity technique to search for gravitational waves.