Fermilab

Quantum Research

Fermilab Quantum Division | Emerging Technologies Directorate

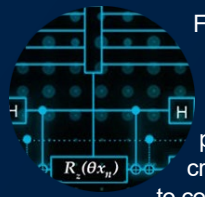
Communication and Networking

Fermilab and its partners are striving to transmit quantum information across greater distances, creating reliable, scalable and secure quantum Building on prior work, the Illinois Express Quantum Network project is developing tools and methods to optimize a quantum network between Fermilab, Argonne National Laboratory, Northwestern University, and University of Illinois at Urbana-Champaign. Their work is furthering under-standing of quantum networks and contributing to realization of a national quantum network.

Sensing and Metrology

Scientists endeavor to detect faint signals from axions, theorized particles of dark matter, by using qubits as sensors. They're trying to coax them out by using a strong superconducting magnet to convert axions into particles of light inside a microwave quantum resonator. Equipped with ultra-sensitive, low-noise quantum electronics, a dark matter detector can be tuned to different frequencies corresponding to signals of axions of different masses so they can seek them in various mass ranges. Fermilab scientists have pioneered the use of super-conducting qubits for single microwave photon counting, which has revolutionized the field of dark matter searches.

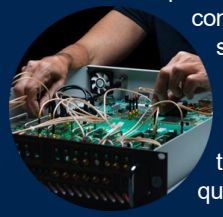
Computing and Simulation



Fermilab scientists are drawing on their strengths in artificial intelligence and microelectronics to accelerate quantum computing performance for high-energy physics applications. They are also creating algorithms to optimize solutions to common particle physics problems, first defining algorithms to solve basic problems and then scaling them up to apply to more complex problems. Meanwhile, theoretical physicists are exploring connections between quantum science and quantum field theory to improve quantum simulations and make calculations more efficient.

Quantum Instrumentation Control Kit - QICK

Fermilab developed QICK, a quantum control and readout system, with support from the Quantum Science Center. Comprised of a radio-frequency circuit board, control and readout electronics, and open-source software, this compact techno-logy replaces traditional hardware, minimizing cost and needed space. Its developers continuously engage the community to extend QICK use for quantum information science and beyond.



Matter-wave Atomic Gradiometer Interferometric Sensor - MAGIS-100

The Fermilab-led MAGIS project, which supports the MAGIS-100 international experi-ment, will use an innovative, 100-meter-long atom interferometer to demonstrate quantum superposition of atoms over a distance of a few meters. MAGIS-100 will be so precise, it will also be capable of detecting tiny changes in gravitational fields which could indicate the presence of dark matter or gravitational waves. Novel technology being developed for MAGIS-100 will pave the way for future experiments with even greater sensitivities.

QUIET Underground Laboratory

Understanding effects of environmental factors like radiation is key to designing more robust qubits or harnessing them as particle sensors. One hundred feet underground, QUIET, along with its surface counterpart, LOUD, will enable controlled experiments comparing environments with signifi-cantly reduced cosmic ray interference to those at the Earth's surface.

U.S. DEPARTMENT of ENERGY

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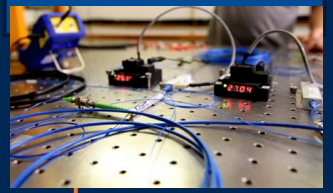
Research Highlights

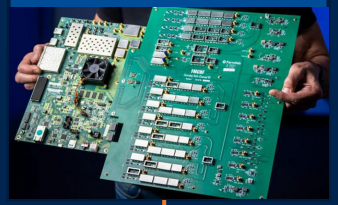
Fermilab Quantum Division | Emerging Technologies Directorate

Dec. 2020: **Researchers achieve sustained, high-fidelity quantum teleportation**

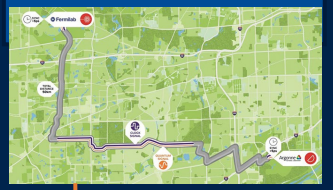


Apr. 2021: **Pioneering use of super-conducting qubits in dark matter detection demonstrates world's lowest noise single microwave photon detector**

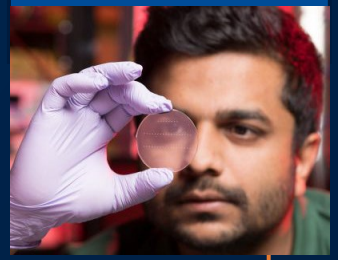
Apr. 2022: **Quantum Instrumentation Control Kit (QICK), open-source control system for quantum computers, makes official debut**



June 2022: **Quantum network between Fermilab and Argonne National achieves laboratory record synch**



May 2024: **Scientists stimulate emission of single photons from dark matter waves, significantly enhancing signals to boost detection**



May 2024: **First measurements of radiation-induced qubit errors performed in Fermilab's underground facility**

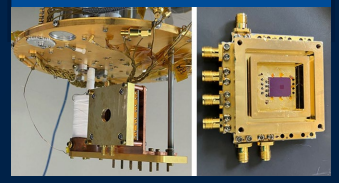
June 2024: **QUIET underground lab opens to study qubits isolated from cosmic radiation**

June 2024: **MAGIS-100 researchers induce clock state transitions in bosons, greatly increasing sensitivity for dark matter and gravitational wave experiments**

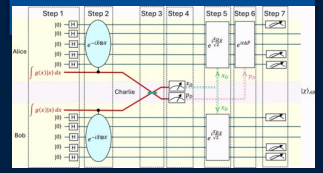
Dec. 2024: **QICK accessory, QICK box, ready to market**

Jan. 2025: **End-to-end machine learning workflow integrated with QICK**

Apr. 2025: **SMSPDs show promise for future particle detectors at Fermilab test beam**



May 2025: **Demonstrated use of squeezed light to dramatically increase the generation rate of entangled pairs over long distances**



July 2025: **Construction of a lab to house a complex laser system for the MAGIS-100 atom interferometer experiment completes**

Sept. 2025: **Optimized SMSPDs tested at CERN, advancing promising technology for next-generation particle detectors**

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