

Research Opportunities

Research Opportunities at Fermilab and SQMS

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SQMS Chief Operating Officer

FARIA – DOE/Fermilab Webinar, February 21, 2024

EXPERIENCE

IN RESEARCH OPERATION

- Physicist Worked on and led mainly International High Energy Physics projects:
 - CERN, Geneva, Switzerland
 - FERMI Lab, Chicago, USA
 - Co-Spokesperson of a project at CERN LHC (2008-2013)

IN SCIENCE POLICY & DIPLOMACY

- Since 2013 Science Counselor at the Embassy of Italy in the USA
 - Covering topics in basic science, energy, and environment.
 - Fostering bilateral S&T collaborations.



Fermilab: US High Energy Physics (HEP) Lab



Particle Physics Lab that **discovered 3 key particles** in the standard model and co-discovered the Higgs boson

Our research is inspired by some of the biggest questions about our **Universe.**

Our mission requires advancing unique accelerator and detector technologies to enable new physics discoveries

Key HEP technologies:

SRF cavities, superconducting high field magnets and materials, cryogenics, detectors, computational tools.









Fermilab \$7B budget

- 3 Main Flagships:
- Accelerator Technologies / PIP-II Neutrino Physics / DUNE
- **Quantum Technologies**

From National Laboratory to International Research Center

•••• Fermilab at a glance today

- The primary DOE laboratory for high energy particle physics & particle accelerators
- About 1,800 staff. 6,800 acres of federal land including restored prairie
- 4,000 scientists from across the U.S. and 53 countries use Fermilab's facilities
- Hosting large experiments on site, at CERN, Canada, Chile, Italy, and the South Pole





•••• PIP-II accelerator

PIP-II will deliver the world's most intense beam of neutrinos to the international LBNF/DUNE project, and enable a broad physics research program, powering new discoveries for decades to come.

Building the world's most powerful neutrino beam cost-effectively



Cooperation with: France, UK, Poland, Italy, India



The Long-Baseline Neutrino Facility (LBNF) supporting the International Deep Underground Neutrino Experiment (DUNE)

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The LBNF/DUNE project is the <u>first internationally conceived</u>, constructed, and operated <u>mega-science project</u> hosted by the Department of Energy in the United States.

204 institutions from 31 countries around the world are participating in the DUNE experiment.

International Collaboration @ Fermilab

- New PIP-II Accelerator, contribution from France, UK, Poland, Italy, India.
- **DUNE** experiment: 204 institutions from 31 Countries
- Since 2022 (Post-Covid) In-person visits from Science Ministries of Czech Republic, France, Italy, Austria....
- Oct. 2022: **NGI** Kick-off Meeting (Horizon Europe Program)

Fermilab played host to international cadre of science counselors

June 27, 2022 | edited by Lisa Roberts

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On Thursday, June 23, under the coordination of the EU delegation to the U.S. and the National Council of University Research Administrators organization, a dozen leading science counselors representing European countries and Canada visited Fermilab to learn about our facilities, science programs and capabilities.



June 2022 visit, organized with NCURA and EU Delegation

U.S. National Quantum Initiative

In 2019 Congress mandated the creation of **Five Dept. of Energy** *National Quantum Centers*

\$625M over five years to develop quantum computers, quantum sensors, and quantum communications

Goal is transformational advances in quantum science and technology

Create a **Quantum Economy**





NATIONAL STRATEGIC OVERVIEW FOR QUANTUM INFORMATION SCIENCE

Product of the SUBCOMMITTEE ON QUANTUM INFORMATION SCIENCE under the COMMITTEE ON SCIENCE of the NATIONAL SCIENCE & TECHNOLOGY COUNCIL SEPTEMBER 2018

> DEPARTMENT OF ENERGY OFFICE OF SCIENCE



NATIONAL QUANTUM INFORMATION SCIENCE RESEARCH CENTERS

FUNDING OPPORTUNITY ANNOUNCEMENT (FOA) NUMBER: DE-FOA-0002253

•••• Fermilab efforts in Quantum Information Science (QIS)

- Why Quantum Science and Technology research at Fermilab? Goal: Leverage Fermilab technology expertise developed for solving HEP problems to the field of QIS, and in turn utilizing QIS advancements to broaden the toolset to enable particle physics discovery
- R&D in the areas of quantum computing, sensing, communication via:
 - Leading and hosting one of the five National Quantum Information Science Research Centers – Superconducting Quantum Materials and Systems Center (SQMS) (\$125M over 5 years, 2020-25)





Canada: Univ. Waterloo Italy: INFN, Univ. Pisa UK: RHUL + NPL

A DOE National Quantum Information Science Research Center, led by Fermilab



A **mission driven**, multi-institutional and multidisciplinary collaboration **leveraging investments** at DOE national labs, academia, industry and several other federal and **international** entities

Introduction to SQMS

 The Superconducting Quantum Materials and Systems Center is one of 5 centers set up under the National Quantum Initiative, hosted by Fermilab with partners at National Labs, Universities and Industry



SQMS Center is located in FNAL Technology Campus, in APS-TD buildings and the IARC building

Availability of existing SRF Materials Science Lab and Quantum Computing Lab allowed Center to "hit the ground running" and focus on science – already generating some important results

Mission: Attacking the Decoherence Cross-Cutting Challenge







SQMS Mission Statement: Bring together the power of National Labs, Industry and Academia to achieve transformational advances in the major cross-cutting challenge of <u>understanding and eliminating the</u> <u>decoherence mechanisms</u> in superconducting 2D and 3D <u>devices</u>, with the goal of enabling construction & deployment of superior quantum systems for computing and sensing.









SQMS S&T Innovation Chain: from material discovery to quantum advantage



SUPERCONDUCTING QUANTUM MATERIALS & SYSTEMS CENTER

Quantum Sensing: new windows into fundamental physics



Dark Matter



Precision Measurements



Gravitational Waves



Quantum Physics

Quantum devices are extremely sensitive to small effects – sensors! New ways to search for dark matter? Searches for new BSM particles? Precision tests of the SM or of QM? New ways to look for gravitational waves?

Fermilab

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Fermilab DarkSRF experiment

#### The 'Quantum Garage' @ the SQMS Center



#### Fermilab South Sou



## **SQMS Ecosystem**



- SQMS strongly emphasizes ecosystem stewardship, partnership synergies
- Training the next generation of scientists and engineers in QIS:
  - Internship programs and Summer schools

# A diverse cohort of > 200 external students + young researchers have been trained to date.

- Quantum Summer School at the Galileo Galilei Institute (GGI) in Florence, Italy, in 2021 + 2022, co-organized with INFN.
- Fermilab hosted the 2023 five NQIRC centers Summer School.





## **SQMS** Quantum Pilot Programs

to establish new collaborations, opportunities, and new breakthroughs

- SQMS launching pilot projects with external collaborators: Unique SQMS infrastructure, capabilities, and expertise on
- 1) Technologies for quantum sensing,
- 2) Quantum materials, and
- 3) Algorithms/simulations, accessible to other research centers, national laboratories, industries and startups
- Mostly in-kind co-share.
- Goal: Identify exciting research opportunities beyond what is currently supported by the Center, to develop valuable collaborative relationships with other institutions, with the particular focus of triggering new collaborations and bridging science and industrial applications.
  Fermilab - Som Som Superconducting QUANTURATION SCIENTING CONTINUE CONTINUE

## **NYU Example**

# RADIOLOGY BUSINESS

Radiology, meet '3D-based superconducting radiofrequency computers'

Dave Pearson | July 21, 2022 | Education & Training





# Quantum MRI (qMRI)

What do you get when you combine MRI with quantum computing? The world will soon find out.

That's because radiology researchers at NYU Langone Health are preparing to partner with scientists and engineers at the Superconducting Quantum Materials and Systems Center, or SQMS. The center is hosted at the U.S. Department of Energy's Fermi National Accelerator Laboratory, aka "Fermilab," in Batavia, Illinois.

The pursuit bringing together investigators from these seemingly disparate fields of inquiry is the advancement of quantitative MRI.

Fermilab's news division covers the development in an item posted July 20.

"We expect to demonstrate that quantum computing can lead to faster and more comprehensive approaches to extract relevant biophysical information from MRI to improve clinical diagnoses," NYU's Riccardo Lattanzi, PhD, tells Fermilab reporter Maxwell Bernstein.



### **Other Opportunities**

In the last 12 months, SQMS has been awarded the following grants:

- DOE-NP Quantum Horizons project, in collaboration w. JLab and Univ. of Waterloo, on "QIS and nuclear physics technologies for next generation materials and architectures for high coherence superconducting qubits".
- DOE-HEP RENEW project, on "Training through research in quantum information science and engineering at the SQMS Center", leveraging SQMS resources and infrastructure to establish new collaborations with Minority Serving Institutions (MSIs). Will engage several MSIs by creating hands-on traineeship opportunities for students and faculty.
- EU Horizon Europe NGI (Next Generation of Internet), on fully paid mobility of EU researchers (3-6 months) to North America institutions. SQMS major partner. Call Opens March 1 Deadline April 15 <u>https://enrichers.ngi.eu/open-calls/</u>



### •••• Horizon Europe @ Fermilab

- Fermilab/SQMS co-applied to the "Horizon Europe" call "Next Generation of Internet" as partner and hosting member, a program funded by the EU Commission for the mobility of young researchers from Europe to North America.
- The program started in 2022 and lasts 3 years. About 70 fellows will join North American institutions for a period up to 6 month each. **NEXT CALL OPENS MARCH 1, 2024!**
- Kick-off meeting at Fermilab on October 11-12, 2022, where the program and the first call of the project was discussed and finalized. With representatives of the different institutions of the consortium: GAC, APRE, AEI, SPI, Enrich Global from EU; Mitacs from Canada; NCURA, Fermilab, Temple University from the U.S.

## **SQMS open to new partnerships**

# Making the whole greater than the sum of the parts

- Cross disciplinary lines
- Share ideas and data
- Be aware of the broader project goals and milestones





### We are on a great journey together



# SOMS Fermilab ENERGY Office of Science



### Thanks

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#### **SPEAKER BIO**

Stefano Lami Ph.D, currently serving as the Chief Operating Officer (COO) at the new National Quantum Information Science SQMS Center. He was the Science Counselor at the Embassy of Italy in Washington D.C. (2013-21), responsible for basic research, energy, and environment. A particle physicist by training, and with decades of experience in science diplomacy and policy, project management in international organizations, Dr. Lami's interests are focused on facilitating international scientific and innovative research collaboration, increasing researcher mobility, and developing research coordination mechanism.

Dr. Lami has participated in numbers of international collaborative project, including:

- Fermi Lab: where the Top quark was discovered, the last foreseen quark particle still to be observed.
- LHC (Large Hadron Collider) at CERN: Co-Spokeperson for the TOTEM Project.
- Researcher and faculty member in University of Heidelberg, Stony Brook University, Rockefeller University.
- Authored and co-authored 600+ scientific publications in peer-reviewed international journals and have been a member of several international scientific committees.

#### Fermilab superconducting cavities: highest coherence time ever demonstrated

A. Romanenko et al, Phys. Rev. Applied 13, 034032, 2020





- Technology originally developed for particle accelerators
- Fermilab is world leader in SRF
- 2 seconds of coherence demonstrated

#### SQMS 3D approach – unique benefits of the world's best coherence

#### **Novel QPU architectures**

- Long coherence allows going from qubit to "qudit" approach (use d energy levels instead of traditional 2)
  - All-to-all qubit connectivity

# **ONE** nine cell SRF cavity + **ONE** transmon = **SQMS 100+** qubits processor



#### Scalability

> 100 qubits with just few input/output lines



#### Science

- Directly probing the quantum to classical transition
  - "Schroedinger cat" states of record large scales
- New physics (dark photon and axion) searches with orders of magnitude improved sensitivity
- Physics simulations enabled by the all-to-all qubit connectivity

#### SQMS goals timeline: a quantum decade leading to new scientific tools



Materials Research for high coherence qubits New quantum testbeds and foundries commissioned

qubit improvement in coherence > 10

Colossal fridge commissioned 20mK Solving complex problems in HEP, CMP, medicine, climate, national security