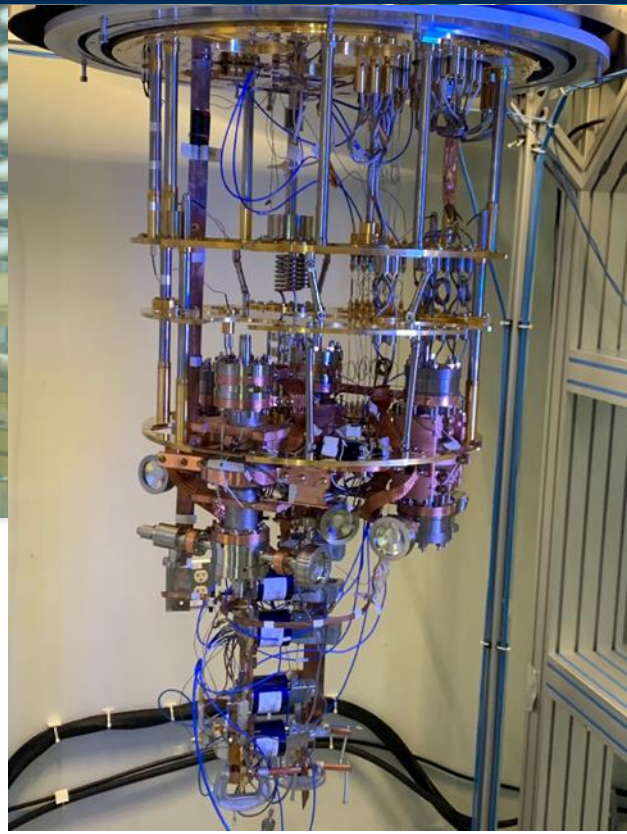


U.S. Funding Opportunities in Quantum Computing for EU Researchers

Stefano Lami, Ph.D.
SQMS Chief Operating Officer

20/09/2022 NCURA – MUNI Workshop, Brno

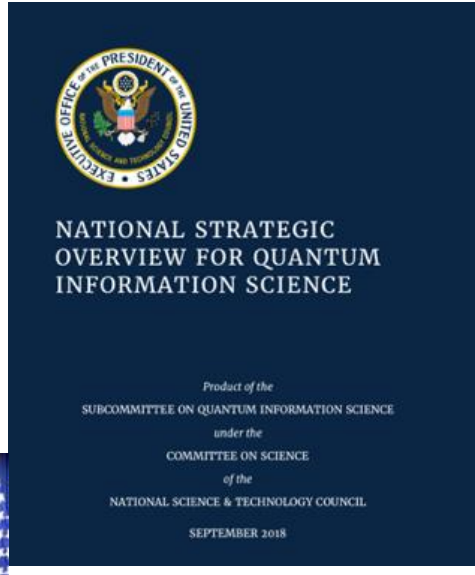
U.S. National Quantum Initiative

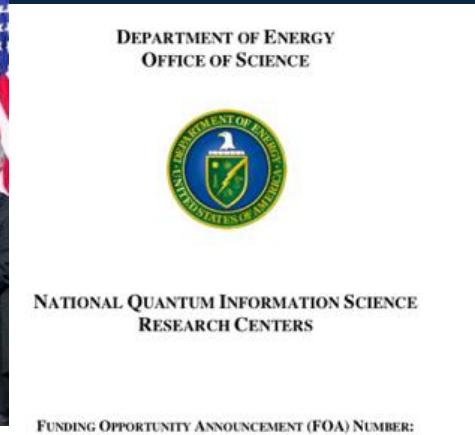
In 2019 Congress mandated the creation of **Five Dept. of Energy *National Quantum Centers***

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

Goal is transformational advances in quantum science and technology

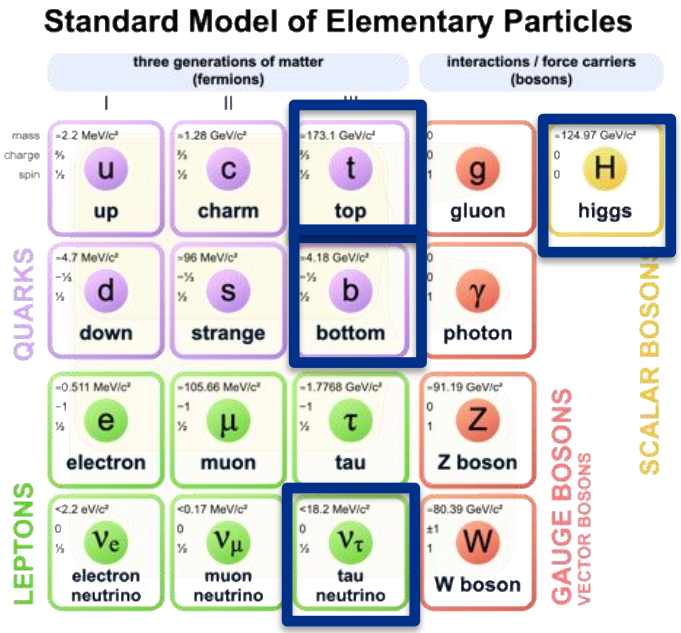
Create a **Quantum Economy**





Fermilab SQMS MATERIALS & SYSTEMS CENTER

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

SQMS SUPERCONDUCTING QUANTUM MATERIALS & SYSTEMS CENTER

Fermilab $7B budget

3 Main Flagships:

Accelerator Technologies / PIP-II

Neutrino Physics / DUNE

Quantum Technologies

From National Laboratory to International Research Center

(4,000 users from 53 Countries)

International Collaboration @ Fermilab

- New **PIP-II** Accelerator, contribution from France, UK, Poland, Italy, India.
- **DUNE** experiment: 204 institutions from 31 Countries
- 2022 In-person visits from Science Ministries of Czech Republic, France, Italy, Austria….
- Oct. 11-12: **NGI** Kick-off Meeting (Horizon Europe Program)

Fermilab played host to international cadre of science counselors

June 27, 2022 | edited by Lisa Roberts

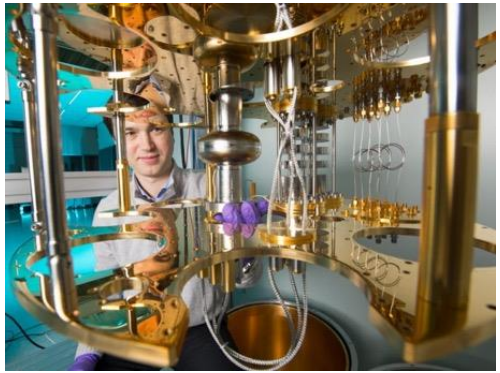
Share Tweet Email

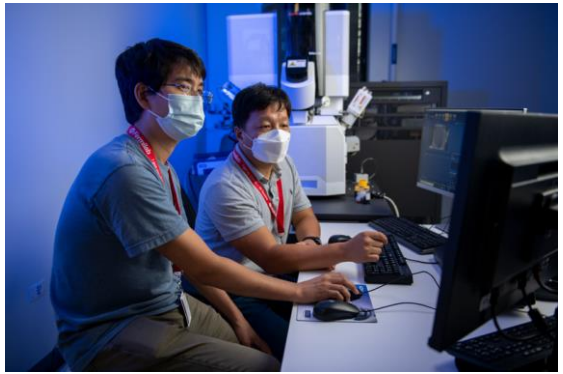
On Thursday, June 23, under the coordination of the EU delegation to the U.S. and the National Council of University Research Administrators organization, a dozen leading science counselors representing European countries and Canada visited Fermilab to learn about our facilities, science programs and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

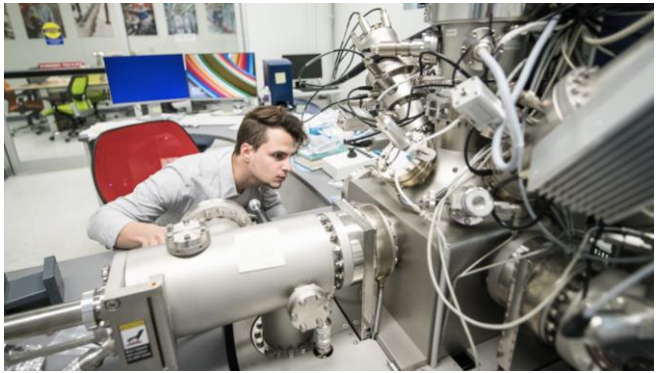
June 23 visit, organized with NCURA and EU Delegation

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)**







Fermilab SQMS SUPERCONDUCTING QUANTUM MATERIALS & SYSTEMS CENTER

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

Fermilab SQMS SUPERCONDUCTING QUANTUM MATERIALS & SYSTEMS CENTER

Superconducting Quantum Materials and Systems Center

A DOE National Quantum Information Science Research Center

23 Institutions
> 400 Researchers

Fermilab · rigetti · Northwestern University · Ames Laboratory · NASA Ames Research Center

NIST · INFN Istituto Nazionale di Fisica Nucleare · Stanford University · University of Illinois Urbana-Champaign · Rutgers · Università di Pisa

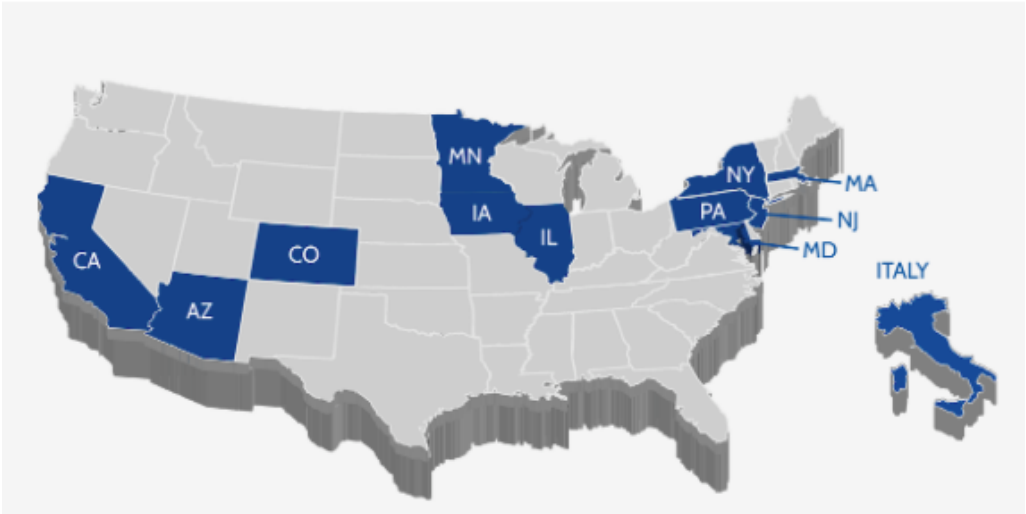
University of Colorado Boulder · Illinois Institute of Technology · Johns Hopkins University · Temple University · Colorado School of Mines · The University of Arizona

University of Minnesota · NYU · Goldman Sachs · Lockheed Martin · Janis · Unitary Fund

> 100 students/postdocs

SQMS by the numbers

81 Committed PIs	**17** Facilities	**733** Involved students
64 Dilution refrigerators	**250K** Sqft. of laboratory space	**122** Publications



Preparing **new partnerships** with UK, Finland, LLNL, U. Michigan and LSU

U.S. Universities in SQMS:

Northwestern
Arizona
Colorado Boulder
Colorado Mines
Illinois Inst. of Technology
Illinois – Urbana Champaign
Johns Hopkins
Minnesota
New York
Rutgers
UC Southern California
Stanford
Temple

Quantum Computing

- **Qubit** = unit of a quantum process, as opposed to a bit in classical computing.
- While a classical bit can only represent as single binary value (0 or 1), a qubit can represent any linear combination of the two values.
- Any system that can exist in a **superposition of states** can be used as qubit. These include resonators, trapped atoms, charge donors in silicon, among others.

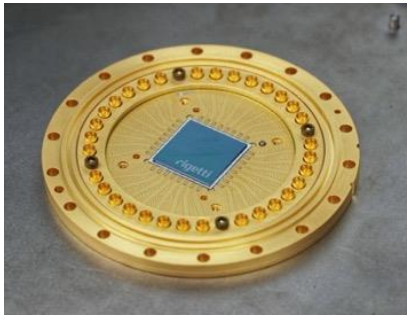
- The **advantage of quantum computing over classical computing** is not one of brute **processing power**, but rather one of addressing **complexity**.
- In complex problems involving, for example, large interconnected databases, a quantum algorithm can approach the problem in a **multidimensional processing space** that reveals connections between widely-separated data points.

SQMS Mission: revolutionary advancements in coherence to reach quantum advantage

- **Coherence time** – the lifetime of quantum states – is currently one of the most important limiting mechanisms of quantum systems and devices
  - **A qubit's coherence time sets the limit** on the achievable circuit depth **in quantum computing**

- **SQMS mission focuses** on advancing coherence of superconducting quantum systems, 2D and 3D, and scaling up, enabling **to build quantum computer prototypes of revolutionary performance**

- Transformational advances possible only thanks to the coordinated effort of unique partners strengths



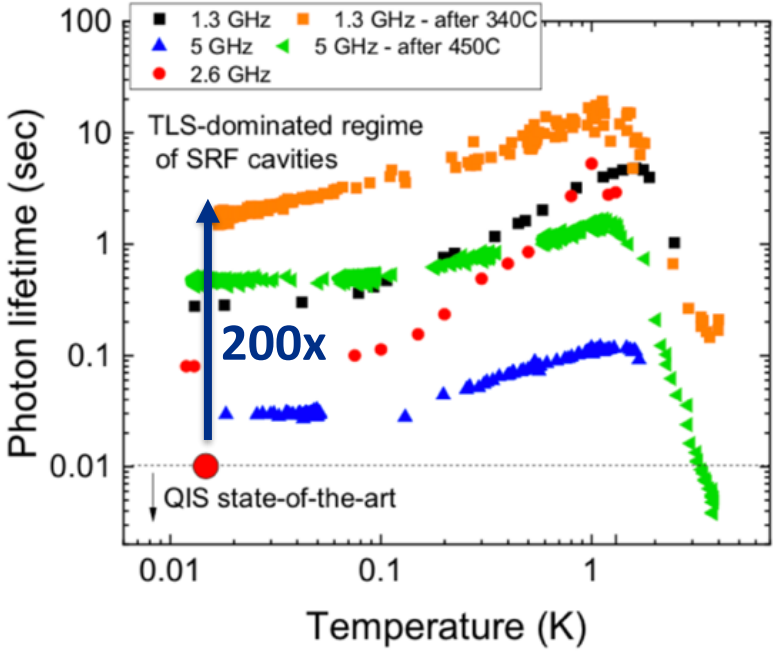
SQMS Mission Statement: **Bring together the power of National Labs, Industry and Academia to achieve transformational advances in the major cross-cutting challenge of understanding and eliminating the decoherence mechanisms** in superconducting 2D and 3D devices, with the goal of enabling construction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

Fermilab

SQMS SUPERCONDUCTING QUANTUM MATERIALS & SYSTEMS CENTER

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**

Fermilab SQMS SUPERCONDUCTING QUANTUM MATERIALS & SYSTEMS CENTER

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

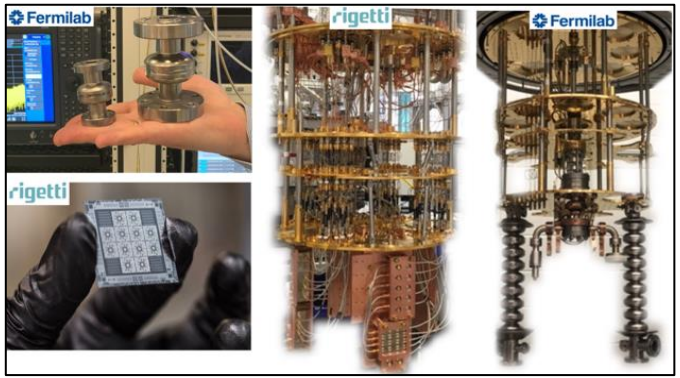
Novel QPU architectures

- Long coherence allows going from qubit to "qu**d**it" 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

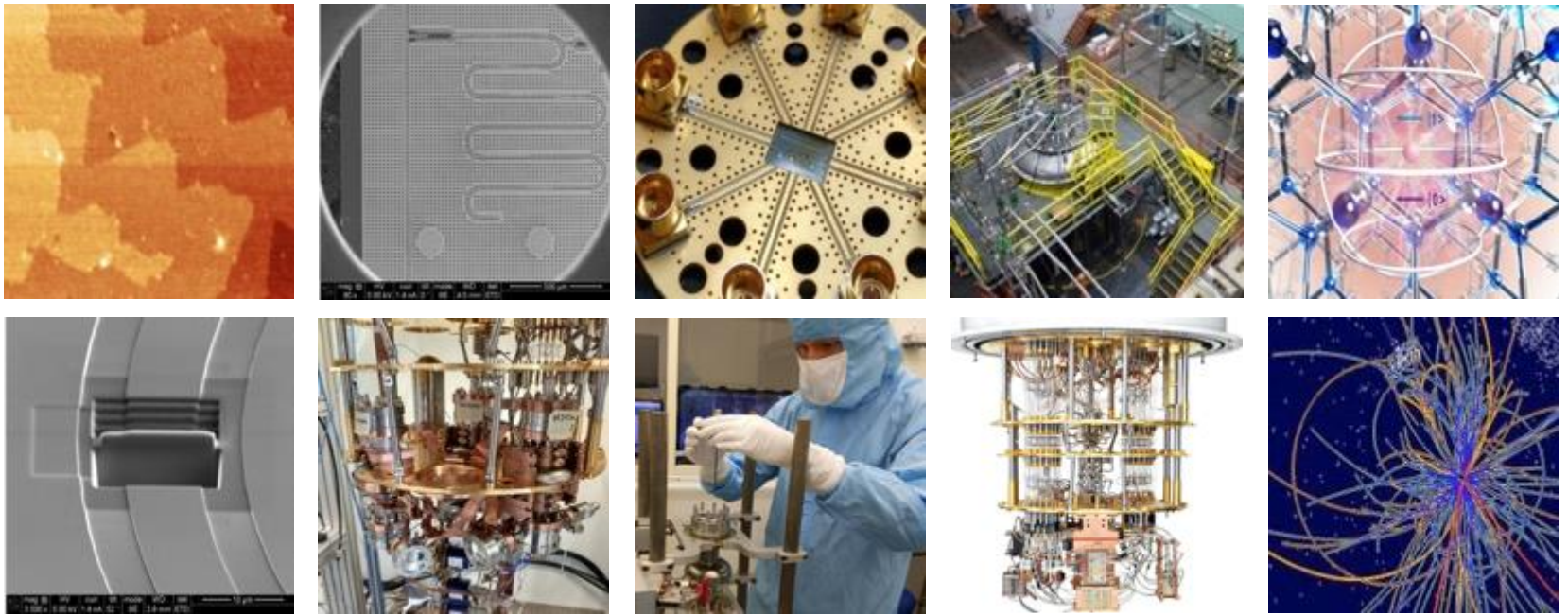


Science

- 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 Roadmap: from material discovery to quantum advantage

Materials Discovery → High Coherence Devices → Systems Integration → New quantum computing and sensing platforms → Quantum Advantage



Potential for physics discovery lays at every step of the chain

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

From 1 - 10 high coherence qubits prototype

Quantum Sensors for fundamental physics

100 qubits Quantum Computer @ Fermilab

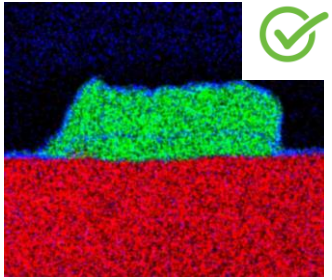
Electronics/optimal controls development

1000 qubits Quantum Computer @ Fermilab

2022

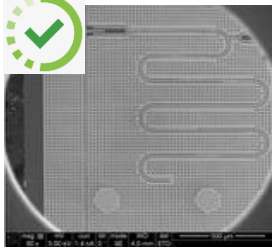
2025 (renewal)

2030



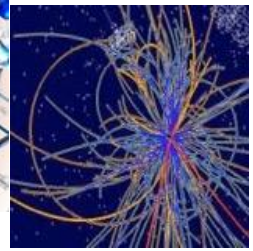
Materials Research for high coherence qubits

New quantum testbeds and foundries commissioned



Commercial transmon qubit improvement in coherence > 10

Colossal fridge commissioned 20mK



Solving complex problems in HEP, CMP, medicine, climate, national security

Fermilab

SQMS SUPERCONDUCTING QUANTUM MATERIALS & SYSTEMS CENTER

SQMS Quantum Pilot Programs

to establish new collaborations, opportunities, and new breakthroughs

- On Oct.2022 SQMS will launch **pilot projects** with external collaborators: **Unique SQMS infrastructure, capabilities, and expertise on technologies for sensing, materials, and algorithms/simulations accessible to other research centers, national laboratories, industries and startups**

- Mostly in-kind co-share. Budget of $300K/year.

- 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.

SQMS Quantum Pilot Program (2)

to establish new collaborations, opportunities, and new breakthroughs

- Examples of areas of **interest** for collaboration with external partners, but not limited to:

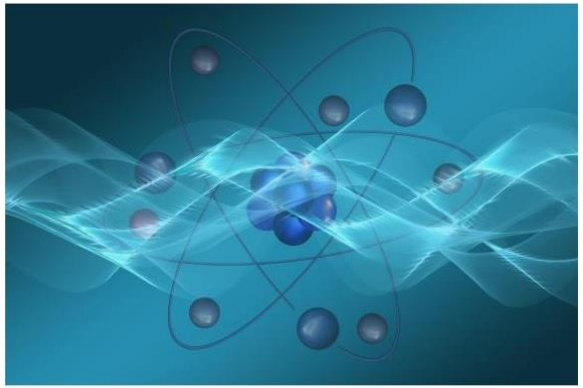
- Technology developed by external collaborators or research programs that are **synergetic** to the SQMS mission and leverage SQMS resources, e.g., facilities and quantum cloud platforms.
- Collaboration on SQMS **materials' testbeds with SRF cavities** which can provide a unique ultrasensitive environment for testing and characterizing the quality of novel qubits and materials for quantum devices, for example topological materials-based that are currently not in the mission of SQMS.
- Collaboration on SQMS transformational quantum computer prototypes in different dilution refrigerators, which can become links to test **quantum network protocols**.
- **Open-source software** projects for the QIS ecosystem and community activities.

NYU Example

Innovate Healthcare
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.

Fermilab SQMS SUPERCONDUCTING QUANTUM MATERIALS & SYSTEMS CENTER

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**.
- In April, the project has been approved for grant by the EU Horizon Europe reviewing committee, and the grant was officially signed in June. The program will start on September 1st and lasts 3 years. About 70 fellows will join North American institutions for a period up to 6 month each.
- **Kick-off meeting** at **Fermilab** on **October 11-12**, 2022, where the program and the first call of the project will be 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.

NGI ENRICHERS

Fellowship program at a glance

TOPICS - NGI related: IoT, 5G, Artificial Intelligence, Big Data, Blockchain, Cloud and Edge computing, Cybersecurity, Quantum Computing and Algorithms and technological foundations

- To **travel to the US or to Canada** and collaborate with their counterparts on NGI related topics
- **3 to 6 months** fellowships (visa, travel and monthly allowance), **100% sponsored**
- To be hosted by **world class US and Canadian universities, research centers, private firms** to jointly develop innovative solutions and services
- 3 competitive **calls (starts end 2022)** with circa **$1.4M to support 70+ NGI Enrichers. Evaluation with involvement of host organisations**

NGI ENRICHERS

Implementing consortium: 11 partners based in European Union, USA, Canada, UK, Ukraine

G.A.C. GROUP Innovation & Performance for Impact

SQMS Fermilab

NCURA Supporting Research...together™

TEMPLE UNIVERSITY®

ENRICH GLOBAL TAKING EUROPEAN INNOVATION GLOBAL

Mitacs

spi Sociedade Portuguesa de Inovação

HEALTHYMITY health decisive analytics with respected anonymity

AGENCY OF EUROPEAN INNOVATIONS

eaec

APRE Agenzia per la Promozione della Ricerca Europea

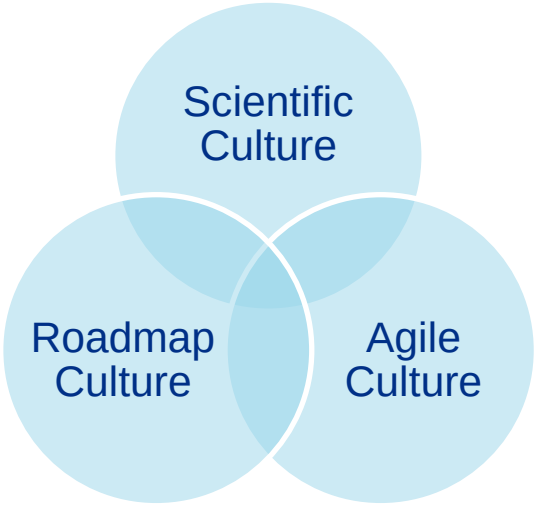
Contact of NGI Enrichers team:

@Fermilab: Dr. Stefano Lami, COO, National Quantum Information Research Center SQMS: lami@fnal.gov
@NCURA: Claire Chen, Director, Global Initiatives: chen@ncura.edu

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

Thanks

lami@fnal.gov