DOE Introductory Remarks: National QIS Research Centers and Superconducting Quantum Materials and Systems Center

Quantum Technologies for Fundamental Physics
Erice, Italy · September 1-7, 2023
https://agenda.infn.it/event/34296/

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U.S. Department of Energy
Office of High Energy Physics

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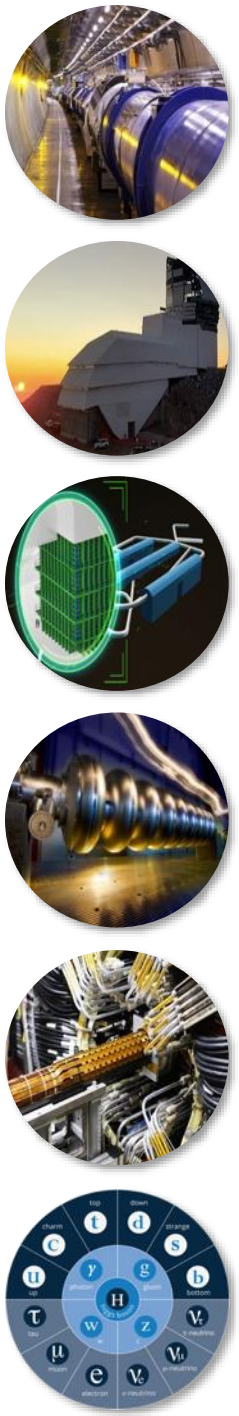

DOE Office of Science Research Portfolio

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Science-Mission driven: *The delivery of scientific discoveries and major scientific tools to transform our understanding of nature and to advance the energy, economic, and national security of the United States*

Advanced Scientific Computing Research (ASCR)	• **Delivering world leading computational and networking capabilities to extend the frontiers of science and technology**
Basic Energy Sciences (BES)	• **Understanding, predicting, and ultimately controlling matter and energy flow at the electronic, atomic, and molecular levels**
Biological and Environmental Research (BER)	• **Understanding complex biological, climatic, and environmental systems**
Fusion Energy Sciences (FES)	• **Building the scientific foundations for a fusion energy source**
High Energy Physics (HEP)	• **Understanding how the universe works at its most fundamental level through research, projects, and facilities operations**
Nuclear Physics (NP)	• **Discovering, exploring, and understanding all forms of nuclear matter**

DOE's 5 National Quantum Information Science Research Centers

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DOE's Office of Science addresses its mission by fostering world-leading science and technology programs and initiatives, including at each of the five QIS Research Centers

Q-NEXT • Next Generation Quantum Science and Engineering
(David Awschalom, Lead: ANL)
Website: https://q-next.org/

Q-NEXT NEXT GENERATION QUANTUM SCIENCE AND ENGINEERING

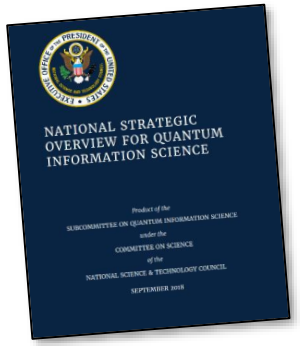
C²QA • Co-design Center for Quantum Advantage
(Andrew Houck, Lead: BNL)
Website: https://www.bnl.gov/quantumcenter/

C²QA

SQMS • Superconducting Quantum Materials and Systems Center
(Anna Grassellino, Lead: FNAL)
Website: https://sqmscenter.fnal.gov/

SQMS

- ✓ Significant Impact to Advance Quantum Research
- ✓ Major Cross-Cutting Challenge
- ✓ Science and Technology Innovation Chain
- ✓ QIS Ecosystem Stewardship
- ✓ Multi-Disciplinary Leadership
- ✓ Well-Structured Plan and Metrics
- ✓ Collaborative Management Structure



National Quantum Initiative Act, passed by U.S. Congress and signed by the President, December 2018

QSA • Quantum System Accelerator
(Rick Muller, Lead: LBNL)
Website: https://quantumsystemsaccelerator.org/

QSC • The Quantum Science Center
(Travis Humble, Lead: ORNL)
Website: https://qscience.org/

QUANTUM SCIENCE CENTER

https://science.osti.gov/Initiatives/QIS/QIS-Centers

DOE Office of Science and QIS

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National QIS Research Centers are a critical part of our QIS Portfolio *and* leverage Office of Science's unique strengths to advance basic science and quantum-based technologies

All of Office of Science, All of QIS

- DOE team approach in processing the funding
- Cross-program coordination of QIS within DOE's Office of Science
- Office of Science-wide and QIS-wide scope, management, and expected impacts

Community Engagement

- Formal Request For Information as a prelude to the funding opportunity announcement
- Stewardship role
- Office of Science website: *https://science.osti.gov/Initiatives/QIS*

Coordination & Partnerships

- Foster coordination and collaborative partnerships among world-leading institutions, including international, through flexible arrangements
- Focus on all levels of the S&T innovation chain
- Executive Council

- QIS Science & Technology (S&T) Innovation Chain
- Advance Key Technical Areas of Interest
- QIS Ecosystem Stewardship
- Instrumentation and Facilities
- Management Structure

SQMS Center

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Today,

- **SQMS is the largest DOE-supported Quantum Center**
- **Brings together more than 450 collaborators across 30 institutions from academia, DOE national laboratories, and industry**
- **Including major international collaborators from world-leading institutes in Italy and the United Kingdom**

Fermilab
Northwestern University
rigetti
AMES NATIONAL LABORATORY
NASA Ames Research Center
NIST
COLORADO SCHOOL OF MINES EARTH • ENERGY • ENVIRONMENT
FormFactor™
Goldman Sachs
ILLINOIS INSTITUTE OF TECHNOLOGY
INFN
Jefferson Lab
JOHNS HOPKINS UNIVERSITY
LOCKHEED MARTIN
LSU
NPL National Physical Laboratory
NYU
ROYAL HOLLOWAY UNIVERSITY OF LONDON
RUTGERS THE STATE UNIVERSITY OF NEW JERSEY
Stanford
Temple University
Unitary Fund
THE UNIVERSITY OF ARIZONA
University of Colorado Boulder
UNIVERSITY OF ILLINOIS URBANA-CHAMPAIGN
UNIVERSITY OF MICHIGAN
UNIVERSITY OF MINNESOTA Driven to Discover®
IN SUPREMÆ DIGNITATIS 1343
UNIVERSITÀ DI PISA
USC University of Southern California
UNIVERSITY OF WATERLOO | IQC Institute for Quantum Computing

National QIS Research Centers: Goals and Progress

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- **Efforts at each National QIS Research Center, including SQMS, are goal-driven and collaborative at a scale and of a type that is different compared to those from other mechanisms of research support**
  - For e.g., they are not single-investigator or small-group research efforts
- **Synergies across disciplines, research sectors, and approaches leading to significant advancements and discoveries**
  - The Centers produce a synthesis across — not just a collection of — various research efforts
- **Focus on advancing the core thrusts defined by each Center's vision and goals**
  - Develop and advance quantum platforms and testbeds to enable quantum computing for the benefit of the broader community
- **A key aspect of each Center is its ability to develop and implement new and unique prototypes, tools, and approaches, and make these available to the broader science and technology community, where appropriate**
- **Regularly assess and discuss the progress towards individual Center's milestones and goals, as well as each Center's impact, by way of annual progress reports, review materials, and other documents**
  - Includes the mid-term reviews held in Feb-Mar 2023 to evaluate progress, goals, and impacts *(more next slide…)*
- **Progress towards collective goals across the Centers are developed and discussed by the Centers' Executive Council *and* by a dedicated QIS Centers' Working Group in DOE's Office of Science**

SQMS Center: Mid-Term Progress Review

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- **Mid-Term Progress Review of each of the five QIS Centers held by DOE during February-March 2023**
  - Evaluated each Center on five merit criteria: technical areas, S&T innovation chain, ecosystem stewardship, management structure, and instrumentation and facilities

- **SQMS reviewed strongly across all 5 criteria elements – some excerpts of the review committee included:**
  - "SQMS **leverages the expertise of Fermilab and a large number of collaborating institutions**. … well established goals and achievements in, and **with first-rate infrastructure** for, quantum SRF cavity measurements and sensor development."
  - "**The Center has a strong effort on moving basic research to industry**. … Industry partners are engaged with the work at each level of the S&T chain. … SQMS uses its strong collaboration with industry to ensure that research efforts align with industry's interests and address core challenges."
  - "**Excellent summer internship program.** … The Center has organized multiple summer schools and workshops, and has participated in the QIS Career Fair organized by the C^2QA Center."
  - "… **Well-defined and strong management team** is in-place **with a "science first" approach that is united to define ambitious goals**, while creating and maintaining an equitable and inclusive environment (**'we are ONE SQMS'**)."
  - **"Based on the reported advancements and breakthroughs, SQMS is currently very well-positioned to play a leading role in QIS research as well as the broader QIS ecosystem."**

SQMS: First-Rate Infrastructure and Facilities

The Quantum Garage at SQMS (Fermilab), together with nanofabrication tools and material science capabilities, are among the largest and most advanced in the world to accelerate QIS research and innovation

SQMS: Initiatives and Achievements

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Key initiatives include

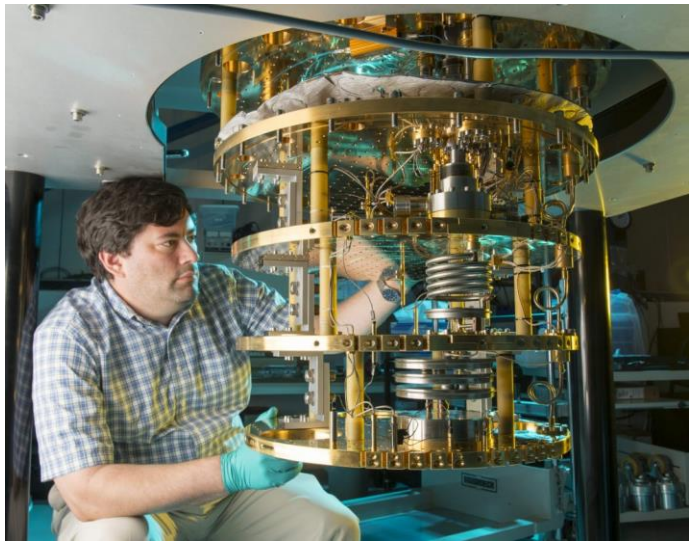
- **Develop and deploy the first quantum computer**
  - Enabled by SQMS team's expertise in superconducting radiofrequency accelerator technology and cryogenics
- **Developing and deploying quantum sensors for fundamental physics and demonstrate qubits of record performance**
  - Realize pilot experiments to advance sensitivity of dark matter searches, precision experiments, & gravitational waves

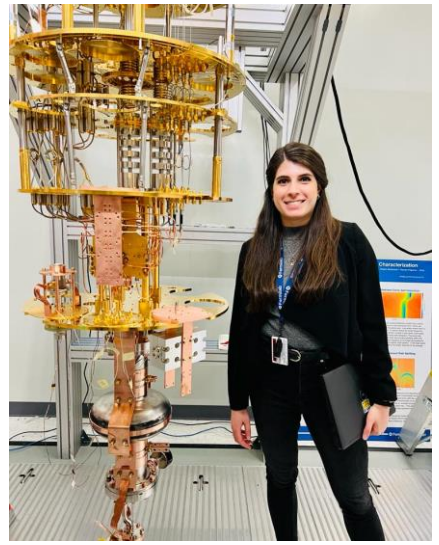
Representative achievements include

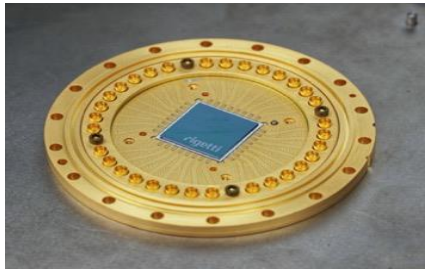
- **Science: world's most stringent limits on dark photon searches using high-Q SRF cavities** (PRL 130, 261801, June 26, 2023)
- **Technology: first 9-qubits quantum processor installed and to-be-operated at the SQMS laboratory**

Active workforce development initiatives, including

- **Largest U.S. summer school for QIS, hosted at SQMS Fermilab in August 2023**
- **40 instructors and top experts in QIS**
- **Educated 150 students and professionals through lectures & laboratory experience**







U.S.-Italy Cooperation in Quantum

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- **Strong and long-standing partnership between Italy and the United States in science & technology cooperation**
- **U.S.-Italy Joint Commission Meeting (JCM) held in Rome in January 2023 reaffirmed the continued cooperation in S&T, including in QIS research**

Key partnership agreements collaboratively advance SQMS research

- **Research Agreement between Fermilab and INFN (Istituto Nazionale Di Fisica Nucleare), signed Feb. 4, 2021**
  - Expertise and critical contributions in underground quantum devices and materials testbed; dark sector particle searches testbeds; and in quantum workforce development initiatives
- **Cooperative Research and Development Agreement (CRADA) between Fermilab and the University of Pisa, to-be-signed very soon**
  - Expertise and critical contributions in quantum computing devices testbed; quantum devices for dark matter and gravitational waves searches; mechanical studies of SQMS's large dilution refrigerator; and algorithms & simulation development

★ ★ ★

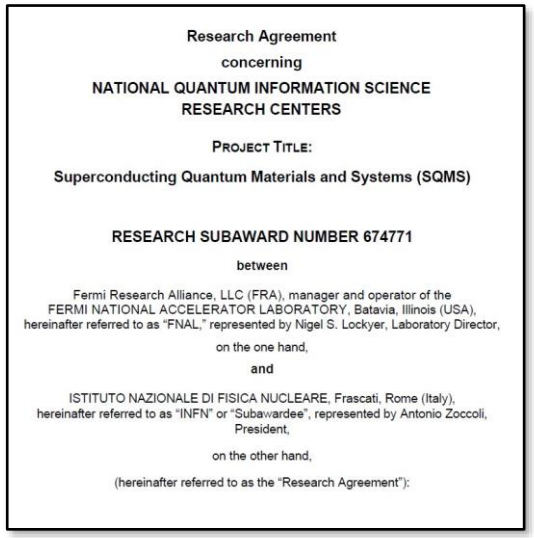
Joint Statement on U.S.–Italy Science and Technology Cooperation

JANUARY 27, 2023

The following joint statement was released by the Governments of the United States and Italy at the 14th meeting of the U.S.-Italy Joint Commission Meeting on Science and Technology Cooperation.

. . .

The JCM, launched 25 years ago, provides a regular opportunity to exchange views on some of the most important science and technology endeavors in our countries and to prioritize future collaboration. This JCM convened representatives from government agencies and research institutions in Italy and the United States to discuss environmental and climate sciences; particle and nuclear physics and astrophysics; health research; and emerging technologies. The two delegations agreed that science and technology cooperation is inspired by democratic values, equity, fair competition, freedom of inquiry, openness, research integrity, and transparency. Both sides endorsed continued research cooperation, including opportunities to enhance collaboration in physics and astrophysics; Earth science, applications, and observations; health and life sciences; climate change and mitigation; advanced materials; quantum information science; digital transition and artificial intelligence; and energy transition.

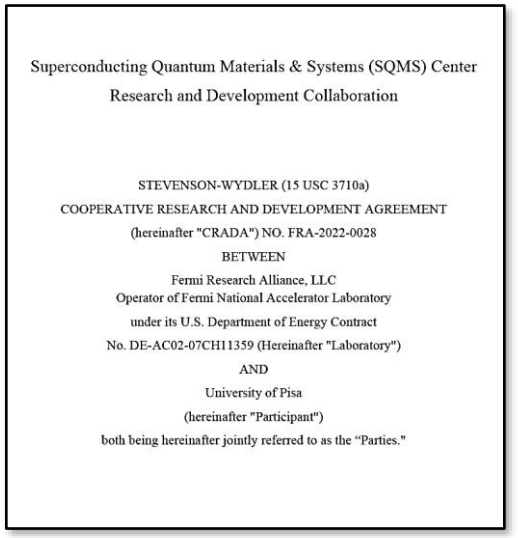


Research Agreement
concerning
NATIONAL QUANTUM INFORMATION SCIENCE RESEARCH CENTERS

PROJECT TITLE:
Superconducting Quantum Materials and Systems (SQMS)

RESEARCH SUBAWARD NUMBER 674771
between

Fermi Research Alliance, LLC (FRA), manager and operator of the FERMI NATIONAL ACCELERATOR LABORATORY, Batavia, Illinois (USA), hereinafter referred to as "FNAL," represented by Nigel S. Lockyer, Laboratory Director,
on the one hand,
and
ISTITUTO NAZIONALE DI FISICA NUCLEARE, Frascati, Rome (Italy), hereinafter referred to as "INFN" or "Subawardee", represented by Antonio Zoccoli, President,
on the other hand,
(hereinafter referred to as the "Research Agreement"):



Superconducting Quantum Materials & Systems (SQMS) Center
Research and Development Collaboration

STEVENSON-WYDLER (15 USC 3710a)
COOPERATIVE RESEARCH AND DEVELOPMENT AGREEMENT
(hereinafter "CRADA") NO. FRA-2022-0028
BETWEEN
Fermi Research Alliance, LLC
Operator of Fermi National Accelerator Laboratory
under its U.S. Department of Energy Contract
No. DE-AC02-07CH11359 (Hereinafter "Laboratory")
AND
University of Pisa
(hereinafter "Participant")
both being hereinafter jointly referred to as the "Parties."

SQMS

SUPERCONDUCTING QUANTUM MATERIALS AND SYSTEMS CENTER

AT A GLANCE

BY THE NUMBERS

Hosted by DOE's Fermi National Accelerator Laboratory, SQMS's mission is to develop beyond-the-state-of-the-art quantum computers and sensors applying technologies developed for the world's most advanced particle accelerators.

RESEARCH SPANS

30 ACADEMIC, NATIONAL LABORATORY, AND INDUSTRIAL INSTITUTIONS

MORE THAN **450** COLLABORATORS ACROSS THE U.S. AND AROUND THE GLOBE

BUILT ON 3 PILLARS

- DEMONSTRATION OF WORLD-RECORD ACCELERATOR CAVITY LIFETIMES IN THE QUANTUM REGIME
- ABILITY TO SCALE UP TO LARGE & COMPLEX MACHINES
- CONTINUE THE LEGACY OF ANSWERING FUNDAMENTAL QUESTIONS IN PHYSICS WHILE ADVANCING NEW TECHNOLOGIES

173 NEW HIRES (TO-DATE, CENTER-WIDE)

OVER **150** STUDENTS & POSTDOCS ADVANCING SQMS GOALS AND MISSION

OVER **200** COMPANIES ENGAGED WITH SQMS (MEMBERS + VENDORS)

MORE THAN **500** EXTERNAL STUDENTS TRAINED THROUGH SQMS SCHOOLS AND INTERNSHIPS

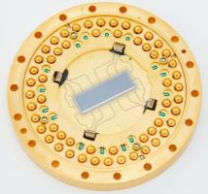
OVER **100** EXPERIMENTS OR INITIATIVES IN QUANTUM RESEARCH

160 PUBLICATIONS (PEER-REVIEWED JOURNALS + ARXIV)

JUST IN FY 2023, PUBLISHED JOURNAL PAPERS **50**

OVER **2 billion** MEDIA IMPRESSIONS TO-DATE

$125 million U.S. FEDERAL FUNDING FOR RESEARCH OVER 5-YEAR PERIOD



>100,000 SQUARE FEET OF SQMS FACILITY & OFFICE SPACE IN USE

10 NEW FACILITIES / TESTBEDS UNDER DEVELOPMENT OR IN PROCUREMENT

Summary Remarks

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- QIS Research Centers build on DOE's long history of stewarding major science and technology initiatives – *i.e.*, the National Nanotechnology Initiative; in Energy – *e.g.*, Bioenergy Research Centers, Energy Frontier Research Centers; in Computing – *e.g.*, Exascale Computing Project, …
- Centers are an integral and leading part of the DOE Office of Science's portfolio and embody a national imperative in terms of urgency, scale, and impact
- SQMS has quickly become an internationally recognized world leader in QIS
- Strong partnerships across many boundaries: agencies, international, industry, labs, and academia
- Excellent progress and impact being made — including stimulating new initiatives as well as the large number of publications by SQMS collaborators — as attested by this year's DOE Mid-Term Progress Review
- DOE appreciates all your work, and I hope you have a pleasant and productive workshop

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