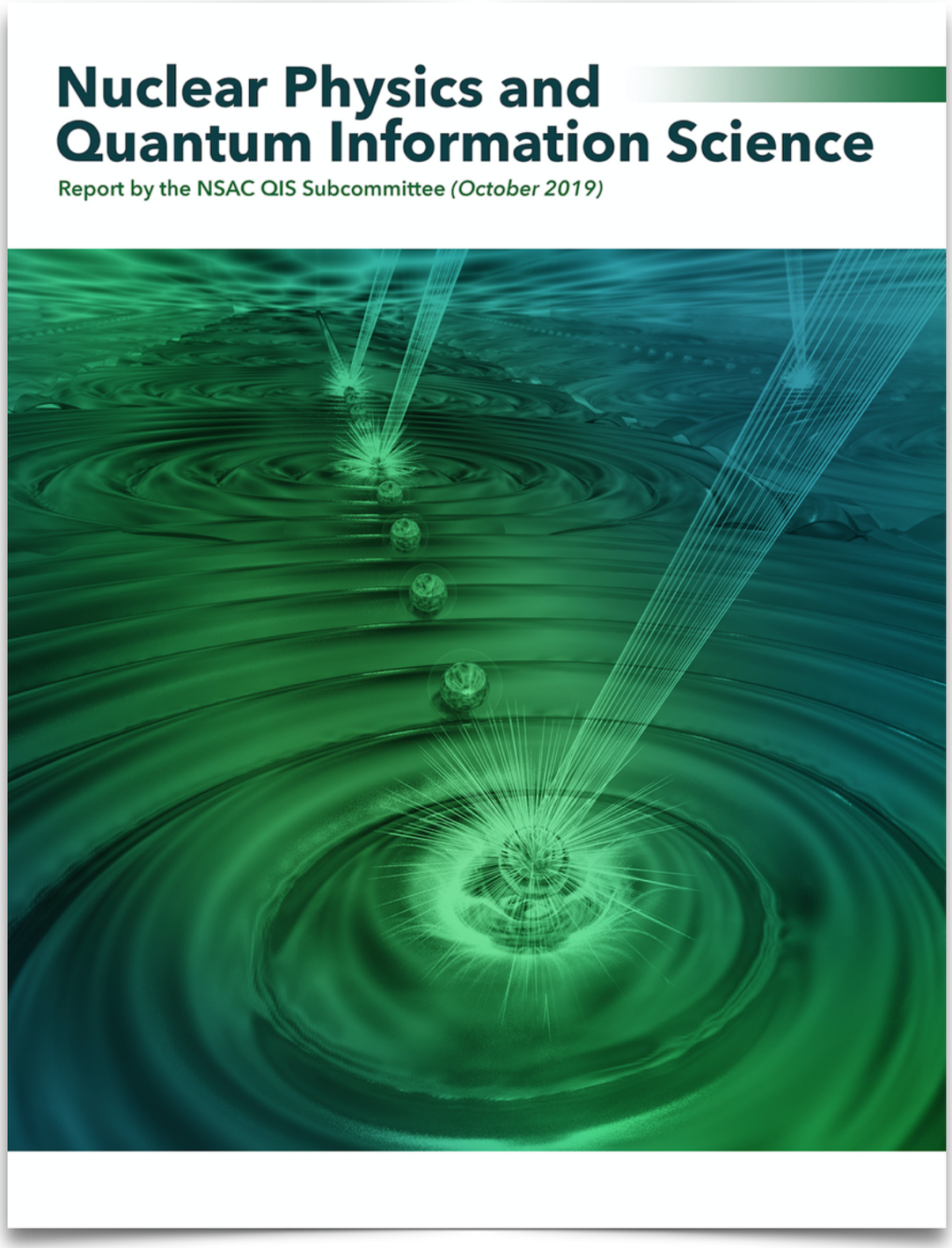


Nuclear Physics and Quantum Information Science
Report to NSAC - October 2019

Washington DC, October 18, 2019 (45 minutes)

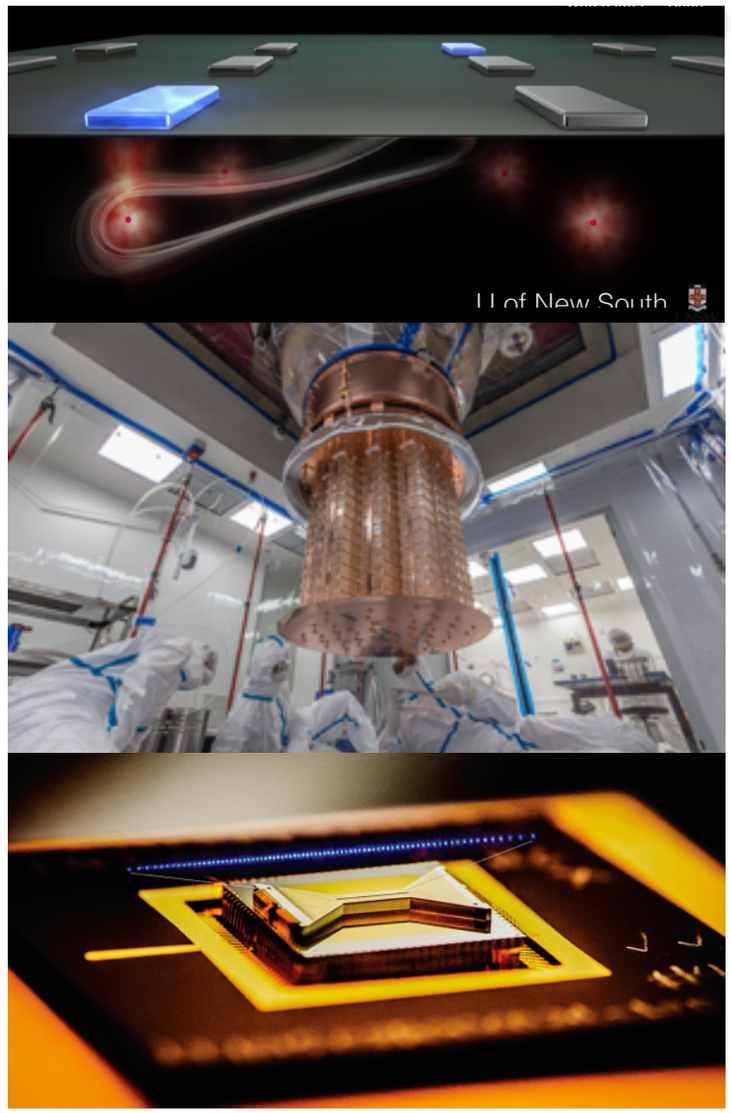
Douglas Beck
Amber Boehnlein
Joseph Carlson
David Dean
Matthew Dietrich
William Fairbanks Jr
Joseph Formaggio
Markus Greiner
David Hertzog
Christine Muschik
Jeffrey Nico
Alan Poon
John Preskill
Sofia Quaglioni
Krishna Rajagopal
Martin Savage (Chair)

Nuclear Physics and QIS

- QIS: the nature, acquisition, storage, manipulation, computing, transmission, and interpretation of information.

- Entanglement and superposition distinguish quantum information from classical information.

- Improving control of superposition and entanglement over macroscopic space-time volumes has produced first devices for quantum computation and quantum sensing

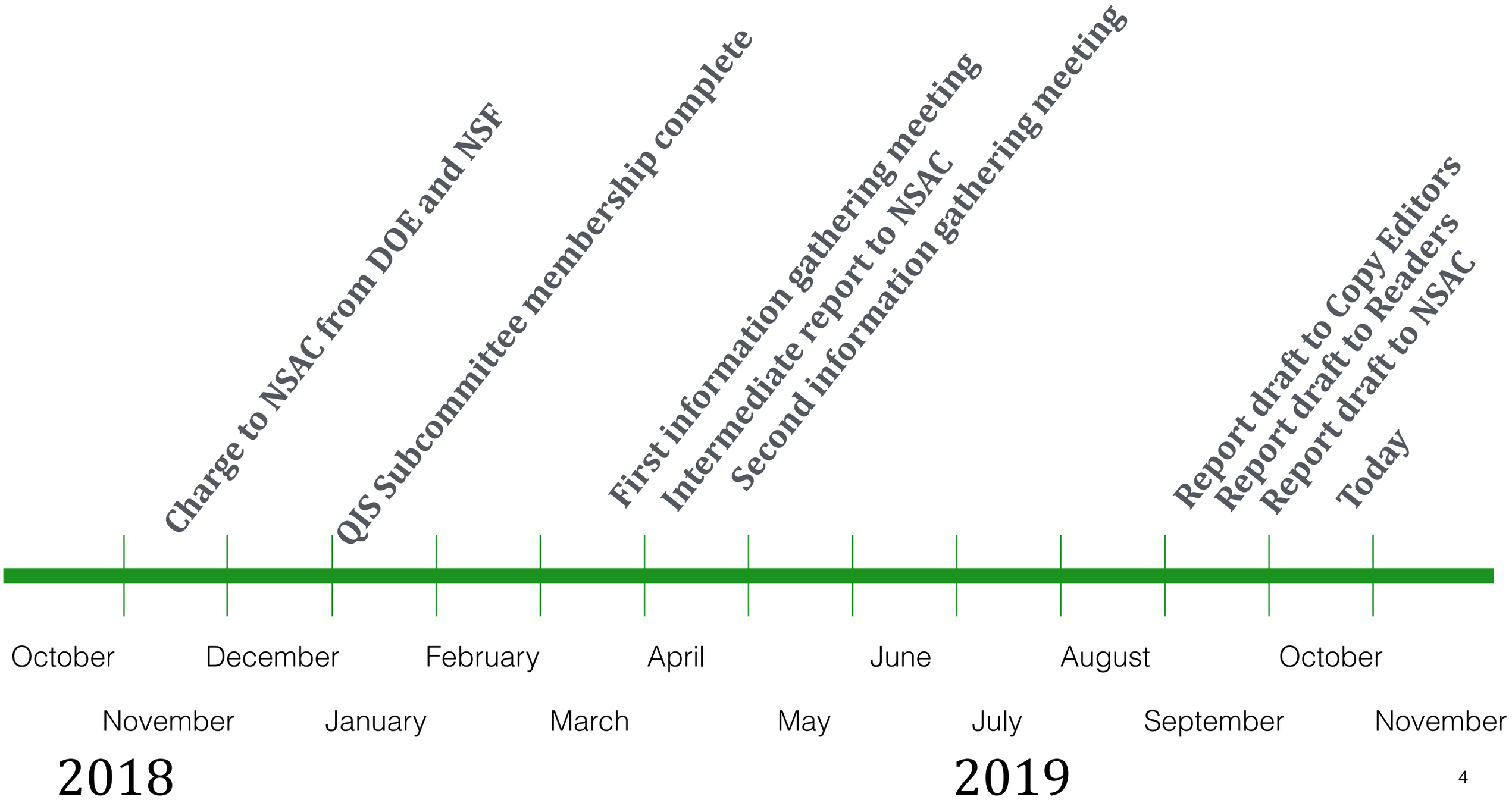


Nuclear Physics can *benefit from* and *uniquely contribute to* advances in Quantum Information Science and Quantum Computing in multiple ways.

NSAC QIS Subcommittee

Douglas Beck	(UIUC)	David Hertzog	(UW) (NSAC Chair)
Amber Boehnlein	(JLab)	Christine Muschik	(Waterloo)
Joseph Carlson	(LANL)	Jeffrey Nico	(NIST)
David Dean	(ORNL)	Alan Poon	(LBNL)
Matthew Dietrich	(ANL) (Co-Chair)	John Preskill	(Caltech)
William Fairbanks Jr	(CSU)	Sofia Quaglioni	(LLNL)
Joseph Formaggio	(MIT)	Krishna Rajagopal	(MIT)
Markus Greiner	(Harvard)	Martin Savage	(INT) (Chair)

NP-QIS Subcommittee Timeline



Introduction to Report

The Charge

> … to provide an assessment of both the potential impact that QIS may have on nuclear physics research programs and new opportunities that may arise,
>
> and to identify unique contributions that NP research could make to the development of QIS.

$$\text{NQI}\ |\mathbf{NP}\rangle \otimes |\mathbf{QIS}\rangle = [\ |(\mathbf{NP\ sensing}\rangle \otimes |\mathbf{QIS}\rangle + |\mathbf{quantum\ many\text{-}body\ and\ QFT\ simulation}\rangle \otimes |\mathbf{QC}\rangle + |\mathbf{Nuclear\ Isotopes}\rangle \otimes |\mathbf{qubits}\rangle + |\mathbf{Low\ Background\ Radioactivity}\rangle \otimes |\mathbf{qubits}\rangle + |\mathbf{NP\ workforce}\rangle \otimes |\mathbf{quantum\ workforce}\rangle + \ldots]/\sqrt{n}$$

MEETING #1

Bethesda, Maryland

Nuclear Physics Exploration of the Quantum Information Science and Quantum Computing Landscape

March 28-29, 2019

Doubletree by Hilton, 8120 Wisconsin Ave, Bethesda, Maryland 20814

NSAC QIS+QC Subcommittee: Meeting #1
NP Exploration of the Quantum Landscape
March 28-29, 2019
Doubletree Hotel, Bethesda, Maryland

Day 1 (Thursday, March 28)

08:00 – 08:30	Executive Session
08:30 – 09:00	Welcome and Subcommittee Orientation **Timothy Hallman (DOE), David Hertzog (UW), Martin Savage (INT/UW)**
09:00 – 09:35	OSTP/NSTC National Strategic Overview for QIS and QC **Jake Taylor (OSTP)**
09:35 – 10:10	The National Quantum Initiative Act **David Dean (Oak Ridge National Laboratory)**
10:10 – 10:35	Coffee Break
10:35 – 11:05	QIS and QC Perspective from NSF **Anne Kinney (NSF)**
11:05 – 11:40	QIS and QC Perspective from NIST **Carl Williams (NIST)**
11:40 – 12:15	QIS and QC Perspective from DOE **Steve Binkley (DOE)**
12:15 – 13:30	Working Lunch
13:30 – 14:05	Overview of the HEP QIS and QC Report **Maria Spiropulu (California Institute of Technology)**
14:05 – 14:40	Overview of the BES QIS and QC Report/Zoom **Giulia Galli (University of Chicago)**
14:40 – 15:15	Overview of the NAS QC Report **Mark Horowitz (Stanford University)**
15:15 – 15:35	Coffee Break
15:35 – 16:10	Overview of the Nuclear Physics QIS and QC Workshops at INT and ANL **Mathew Dietrich (Argonne National Laboratory)**
16:10 – 17:30	Executive Session
17:30	Adjourn Day 1

Context

Agencies

Photo !!!

Related domains and NAS

Nuclear Community

Day 2 (Friday, March 29)

8:15 – 8:45	An Overview of QIS and QC programs in Europe/Zoom **Tommaso Colarco (Forschungszentrum Juelich)**
8:45 – 9:15	An Overview of QIS and QC programs in China/Zoom **Jian-Wei Pan (University of Science and Technology of China)**
9:15 – 9:45	An Overview of QIS and QC programs in Canada **David Cory (University of Waterloo)**
9:45 – 10:05	Coffee Break
10:05 –10:35	QIS and QC Interest of laboratories in the Northeast **Eden Figueroa (Stony Brook University)**
10:35 –11:05	QIS and QC Interest of laboratories in the Midwest/Zoom **Salman Habib (Argonne National Laboratory)**
11:05 –11:35	QIS and QC Interest of laboratories in the West Coast **Irfan Siddiqi (University of California, Berkeley)**
11:35 –12:05	QIS and QC Interest of laboratories in the Southeast **David Dean (Oak Ridge National Laboratory)**
12:05 – 13:30	Working Lunch
13:30 – 14:00	Overview of ASCR QIS and QC Programs **Barbara Helland (DOE-ASCR)**
14:00 – 14:30	Overview of NP QIS and QC Programs **Timothy Hallman (DOE-NP)**
14:30 – 15:00	Isotopes for QIS and QC **Joel Grimm (DOE-NP)**
15:00 – 15:20	Coffee Break
15:20 – 16:20	Executive Session
16:20	Adjourn Meeting

International

Labs and Regional

ASCR Nuclear Programs

Appendix C: Agenda of Meeting 2

A Deep Dive
April 30–May 1, 2019
UW Club, Yukon Room, University of Washington, Seattle

Day 1 (Thursday, April 30)

08.00 – 08.30: Executive Session

08.30 – 09.00: Technology for EDM Detection **Matthew Dietrich (ANL)**

09:00 - 09.30: Superconducting Qubits for QIS and QC **Brent VanDevender (PNNL)**

09:30 - 10.00: Superconducting Cavities and QIS **Alexander Romanenko (FermiLab)**

10:00 – 10:30 **Coffee Break**

10:30 – 11:00: Quantum Electron Microscopy **Mark Kasevich (Stanford)**

11:00 – 11:30: Quantum Encryption and Quantum Communication
Christine Muschik (University of Waterloo)

11:30 – 12:00: Quantum Defects for Sensing and Computing, and Isotopic Purity
Xing Rong (University of Science and Technology in China)

12:00 – 12:30: Overview of Quantum Sensors **Joel Ullom (University of Colorado/NIST)**

Sensors

12:30 – 13:30 **Lunch**

13:30 – 14:00: QIS and QC Interests of LANL, LANL and Sandia **Richard Muller (Sandia)**

14.00 – 14.30: Superconducting Nanowire Single-Photon Detectors and Transition Edge Sensors
Aaron Miller (Quantum OPUS)

14.30 – 15.00: Quantum Sensors in High-Sensitivity Experiments
Gray Rybka (University of Washington)

15:00 – 15:30 **Coffee Break**

15:30 – 16:45: **Technology Panel** on Engagement and Collaboration with Universities and Labs

45 minutes: presentations by each panel member (**15** minutes each), followed by

30 minutes of Q&A

Panelists: 1) D-Wave—**Eric Ladizinsky**, 2) Google—**Dave Bacon,** 3) IBM—**Jerry Chow**

16:45 – 18:30: Executive Session

18.30: **Adjourn Day 1**

Tech Companies

MEETING #2

Seattle, Washington

Quantum Computing and Quantum Information Science: A Deep Dive

April 30 - May 1, 2019

University of Washington, HUB

Day 2 (Friday, May 1)

08.00 – 08.30: **Executive Session**

08.30 – 09.00: Quantum Simulation **Matthias Troyer (Microsoft)**

09:00 - 09.30: Atoms, and Engineering Challenges **Markus Greiner (Harvard)**

09:30 - 10.00: Ions, RF, and Optical Engineering—IonQ **Jungsang Kim (Duke/IonQ)**

10:00 – 10:30 **Coffee Break**

10:30 – 11:00: QIS and QC with Photons **Pavel Lougovski (ORNL)**

11:00 – 11:30: Qudits @ LLNL **Jonathan Dubois (LLNL)**

11:30 – 12:00: Theoretical Advances for QIS and QC **John Preskill (Caltech)**

12:00 – 12:30: Overview of Quantum Simulations for NP **David Kaplan (INT)**

Quantum Computing

12:30 – 13:30 **Lunch**

13:30 – 15:00: Subcommittee Deliberations

- Compile Subcommittee Comments
- Establish Findings for the Report

Committee Deliberations

15:00 – 15:30 **Coffee Break**

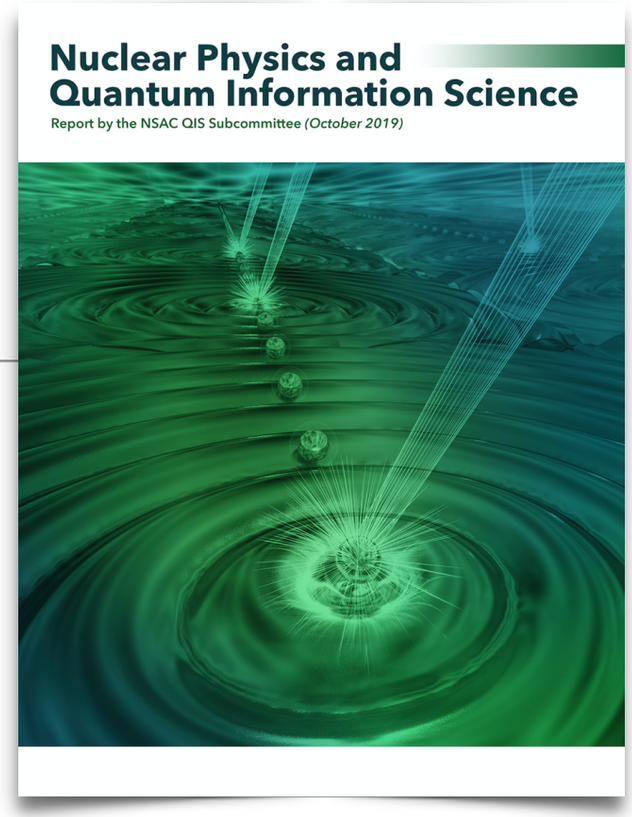
15:30 -16.30: Subcommittee Deliberations

16.30 – 17.30: Formulate Draft Recommendations

- Finalize Report Writing Assignments

17.30: **Adjourn Day 2**

Report Scope



Addressed the Charge in detail

- **QIS for NP and NP for QIS**
- experiment, theory and computation
- NP-QIS is the focus
  - identified synergies with other domains
  - sidebars for highlights and state-of-the-art presentation

Developed a "vision" for the path forward for NP

- **Recommendations and Comments**
  - agencies, DNP, community, journals, ….
  - did not develop implementation plan
  - aspects could be scaled up to include HEP and BES
  - collaborative, multi-disciplinary efforts beyond what we have seen

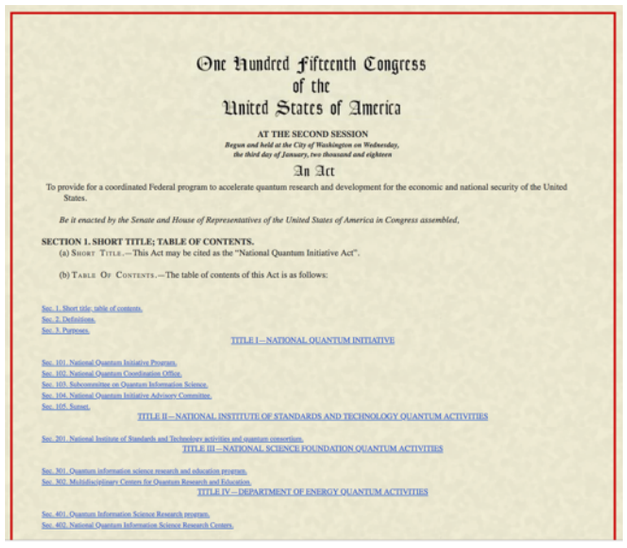
Introduction to QIS and its relationship to NP

- did not discuss/address quantum communication or memory or …

US National Quantum Initiative

https://www.congress.gov/bill/115th-congress/house-bill/6227/text

The National Quantum Information (NQI) Act, passed in 2018.
NQI shall:



One Hundred Fifteenth Congress
of the
United States of America

AT THE SECOND SESSION
Begun and held at the City of Washington on Wednesday, the third day of January, two thousand and eighteen

An Act

To provide for a coordinated Federal program to accelerate quantum research and development for the economic and national security of the United States.

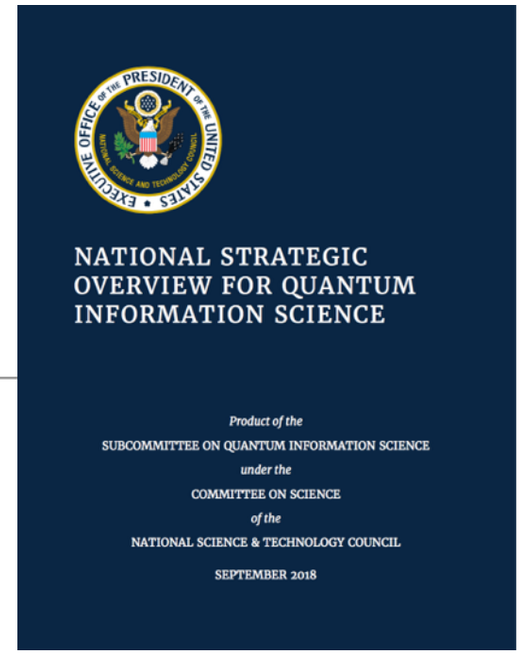
Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled,

SECTION 1. SHORT TITLE; TABLE OF CONTENTS.

(a) SHORT TITLE.—This Act may be cited as the "National Quantum Initiative Act".

(b) TABLE OF CONTENTS.—The table of contents of this Act is as follows:

Sec. 1. Short title; table of contents.
Sec. 2. Definitions.
Sec. 3. Purposes.
TITLE I—NATIONAL QUANTUM INITIATIVE
Sec. 101. National Quantum Initiative Program.
Sec. 102. National Quantum Coordination Office.
Sec. 103. Subcommittee on Quantum Information Science.
Sec. 104. National Quantum Initiative Advisory Committee.
Sec. 105. Sunset.
TITLE II—NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY QUANTUM ACTIVITIES
Sec. 201. National Institute of Standards and Technology activities and quantum consortium.
TITLE III—NATIONAL SCIENCE FOUNDATION QUANTUM ACTIVITIES
Sec. 301. Quantum information science research and education program.
Sec. 302. Multidisciplinary Centers for Quantum Research and Education.
TITLE IV—DEPARTMENT OF ENERGY QUANTUM ACTIVITIES
Sec. 401. Quantum Information Science Research program.
Sec. 402. National Quantum Information Science Research Centers.



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

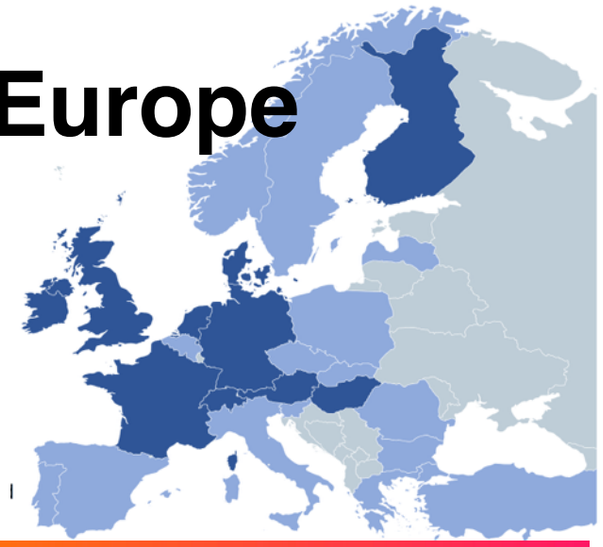
- establish a **10-year plan** to accelerate basic research in QIS and relevant technological applications
- invest in fundamental QIS&T R&D and other to accomplish these goals
- invest in activities to develop a QIS&T worksforce pipeline
- provide for interagency planning and coord. of QIS R&D and other
- partner with industry and universities to leverage knowledge and resources
- leverage existing investments to advance goals and priorities

QIS development (QC, sensing, communications, networking, memory,..) coordinated by NSTC

Current R&D efforts organized around 3 pillars: civilian, defense, and intelligence communities

Accelerating International Quantum Investments

Europe

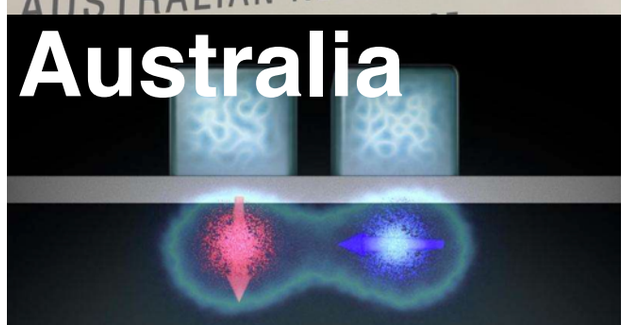


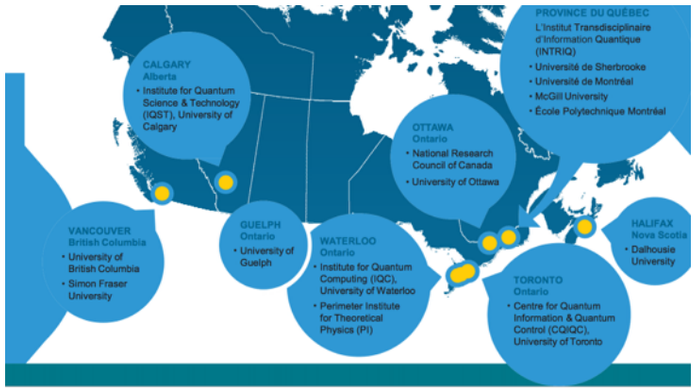
QUANTUM FLAGSHIP

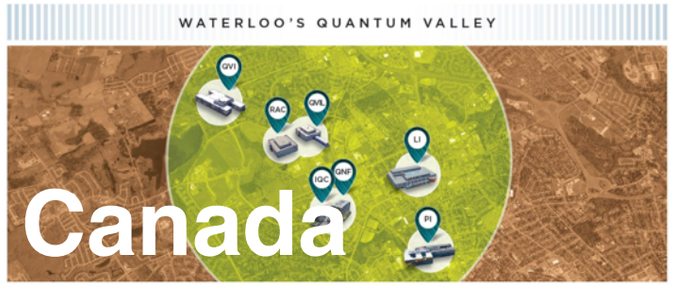
CENTRE FOR QUANTUM COMPUTATION & COMMUNICATION TECHNOLOGY

AUSTRALIAN RESEARCH COUNCIL

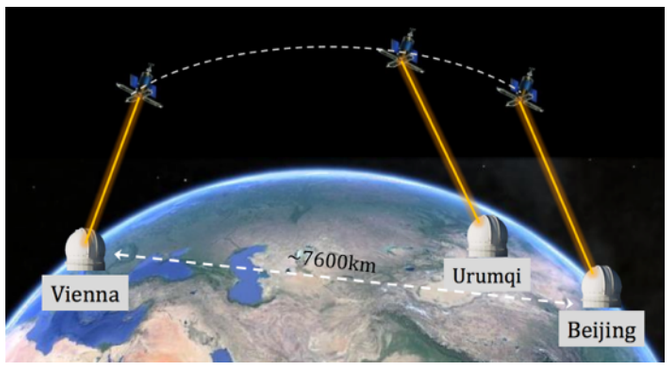
Australia



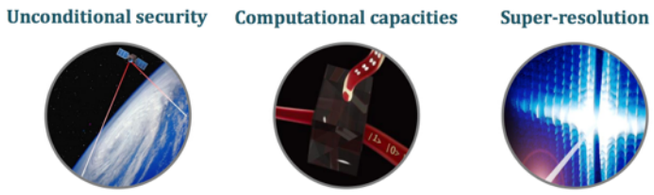


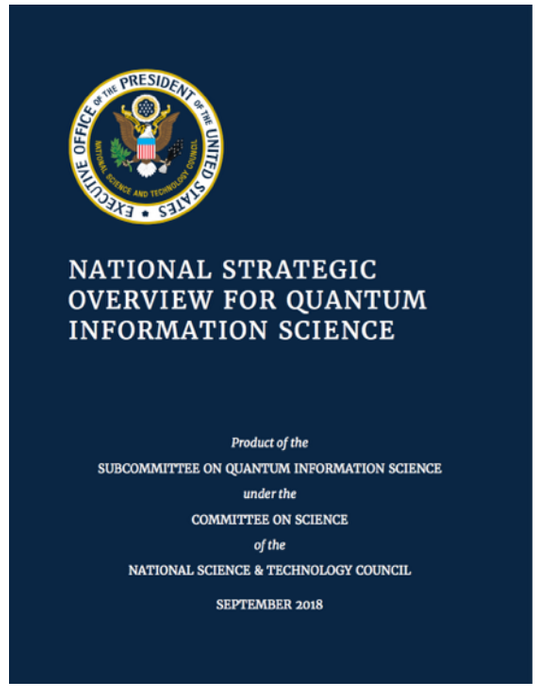


Canada



China





USA

+ ...

At “Scale” - potentially a `Silicon-sized” quantum economy

Quantum Ecosystem

National Laboratories

Universities

Government Agencies

Technology Companies,Startups

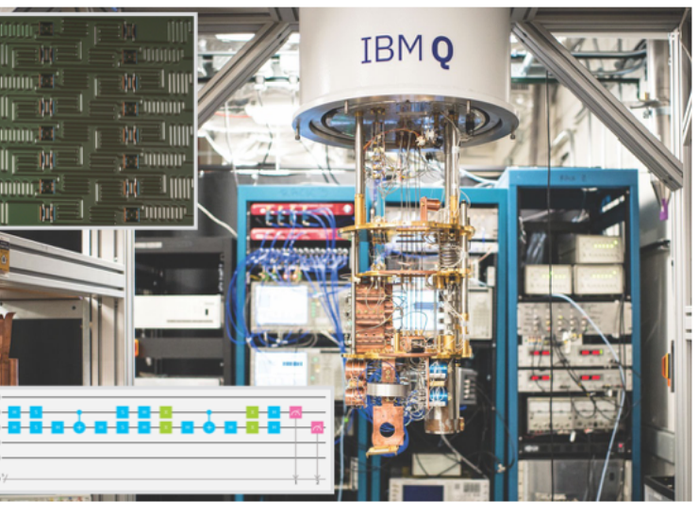
Investors

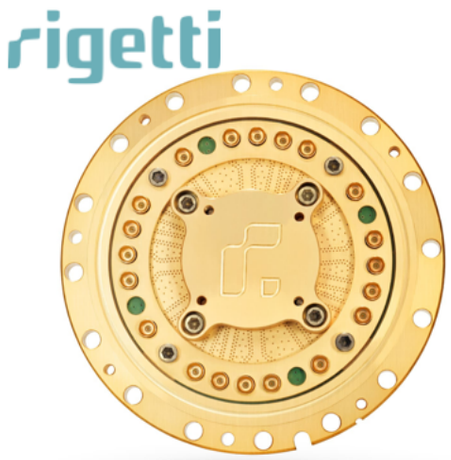
Manufacturing Sector

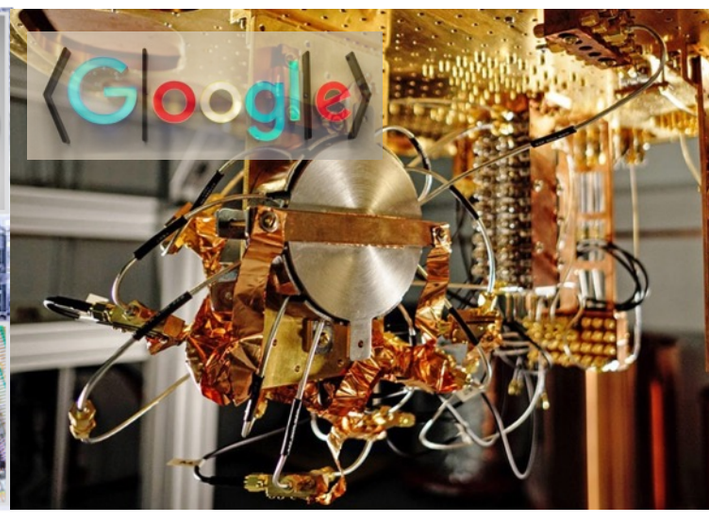
Quantum Economic Development Consortium

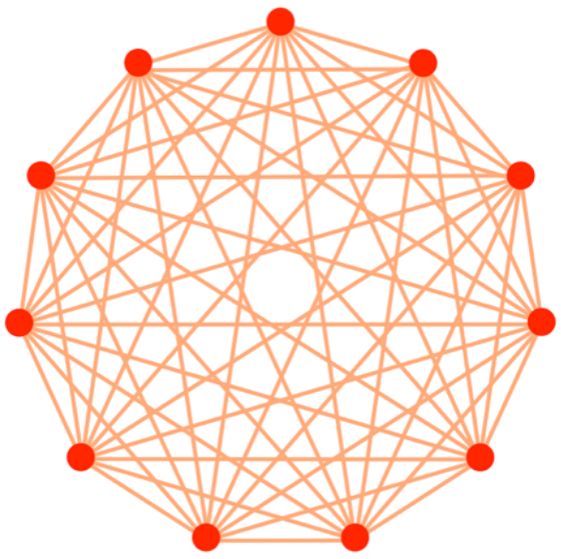
First Quantum Devices for Scientific Applications

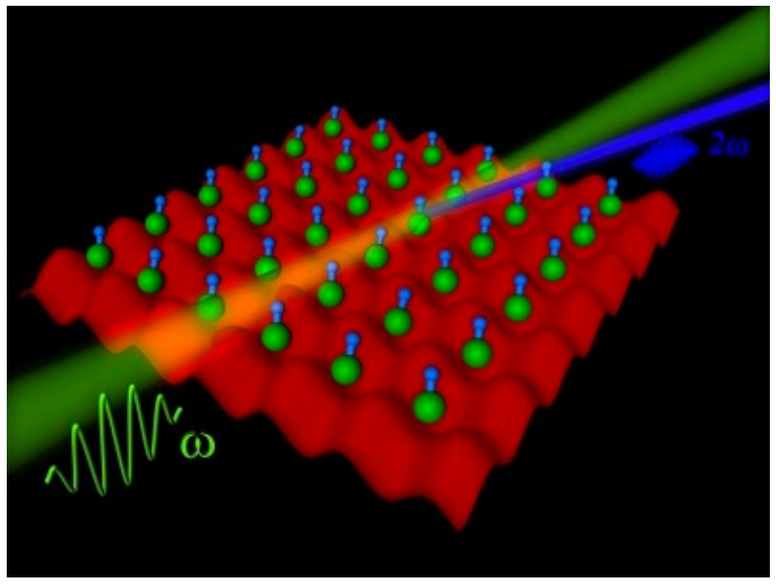
Quantum devices will likely always be embedded in large classical computing environments











Hemmerling, Cornel, https://www.photonics.com/Article.aspx?AID=64150

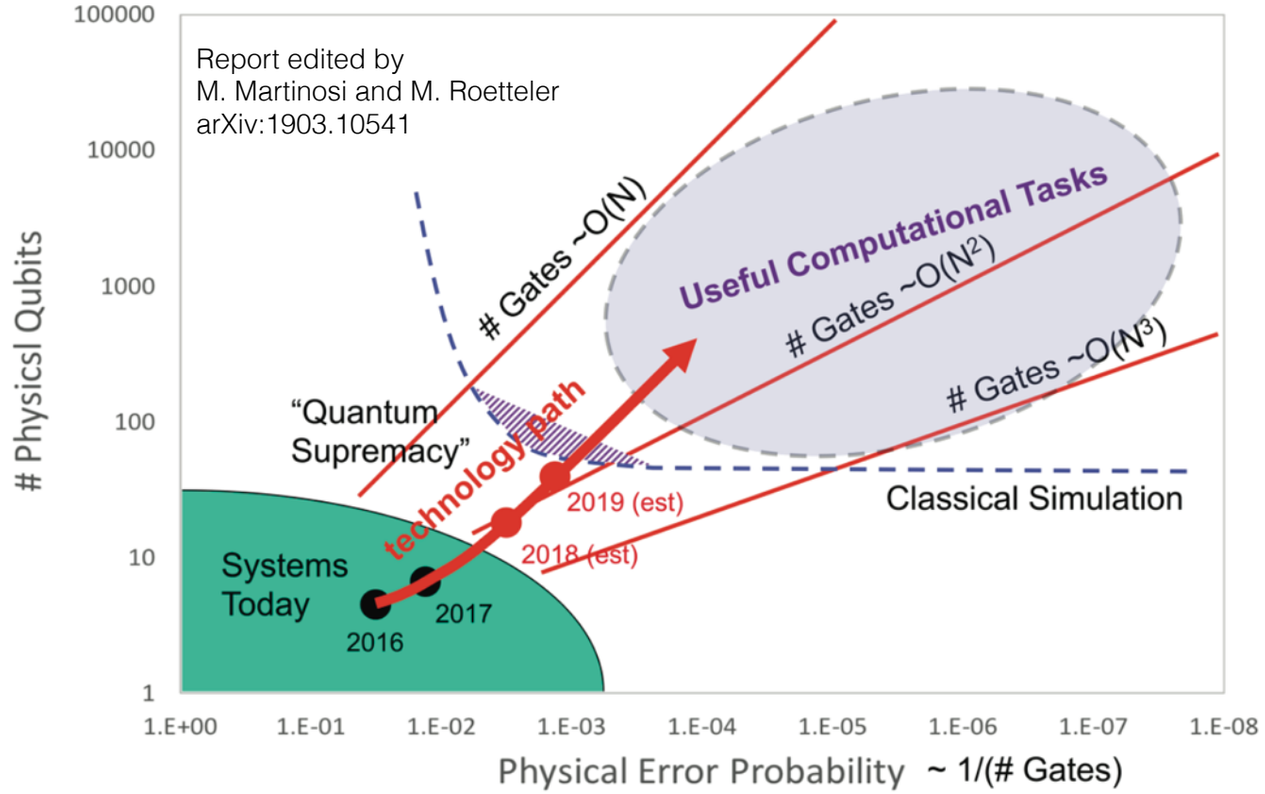
NISQ-era quantum devices for applications

Simulations in the NISQ-Era - the next decade

- Minimal or no error correction in hardware or software
- A few hundred qubits with modest gate depth
- Imperfect quantum gates/operations - like ``running experiments''
- Different ``flavors''

John Preskill - Jan 2018

- NISQ-era is the next decade of quantum simulation
  - much to be gained during this period
  - learn by doing - just like all experiments
- Searching to find Quantum Advantage(s) - ``the rumor''??



Quantum Sensing

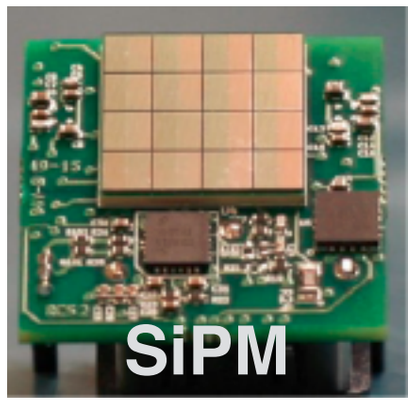
Quantum 1.0 sensors - measure a quantum property, such as one photon

- critical in research, medicine, telecommunications, and computing - major component of economy

Advanced:

Transition edge sensors, superconducting nanowire single photon detectors, microwave kinetic inductance detectors, and Josephson parametric amplifiers are entering experimental physics programs.

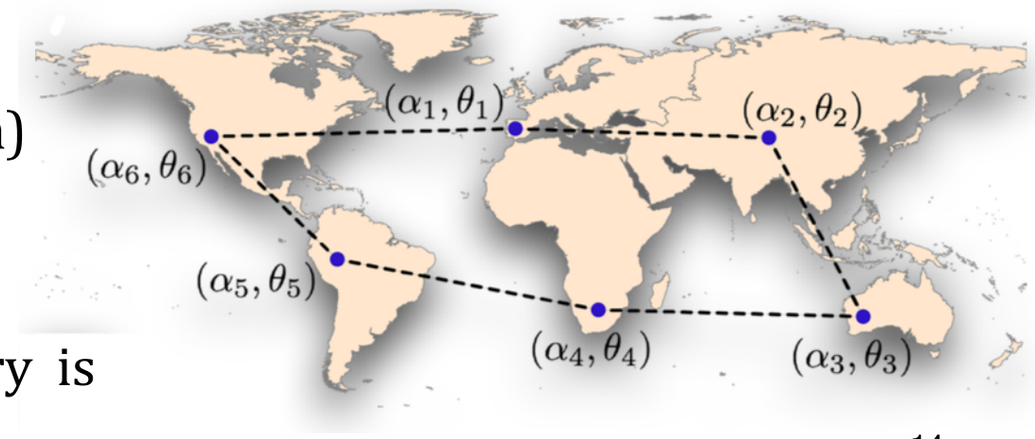
- Astro, AMO, BES, HEP, NP, …
- CMB, sub-millimeter astro, DM, NP program….



Quantum 2.0 sensors - make use of superposition, entanglement, or squeezing

- nascent, largely research, profound potential

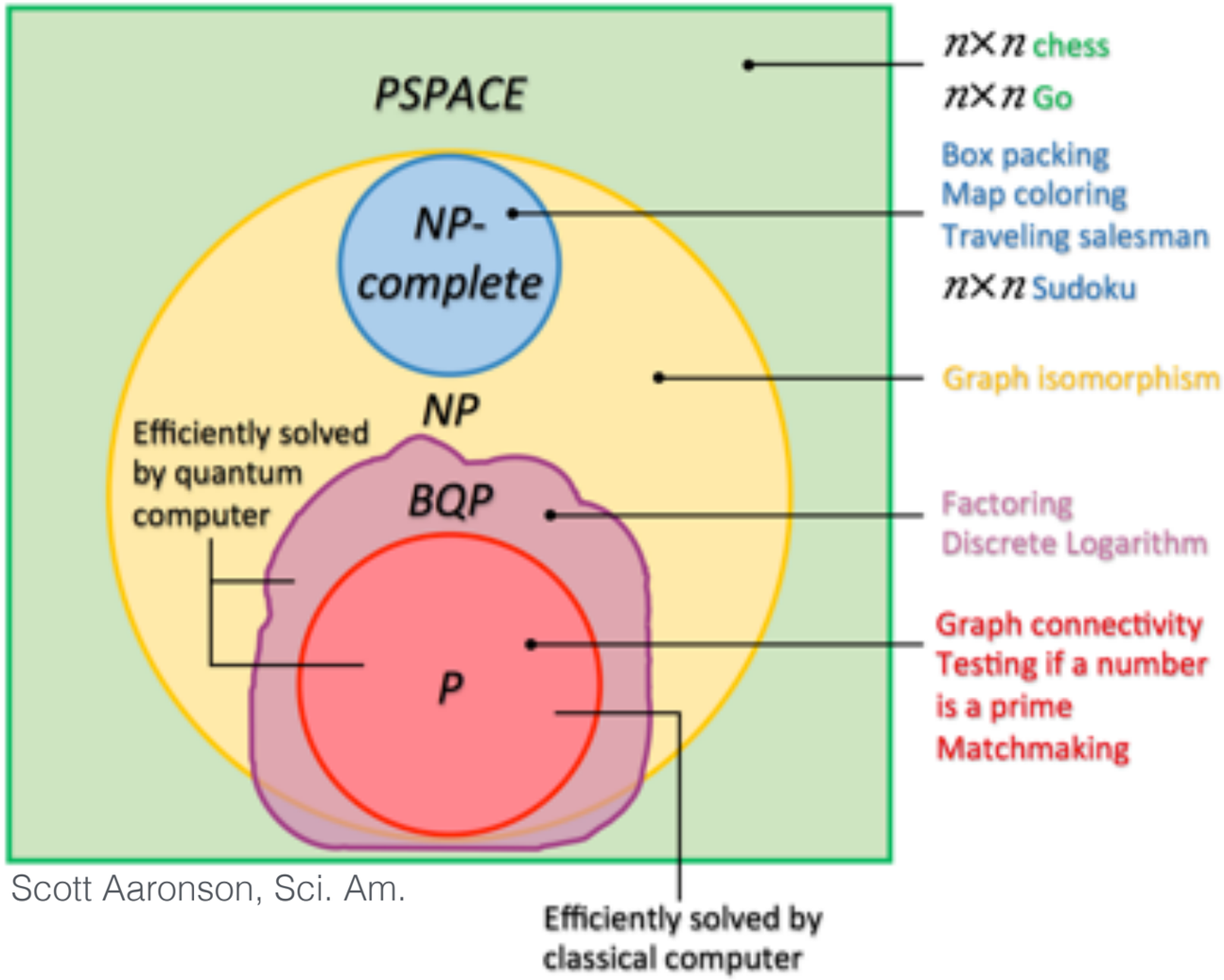
- precision measurements (magnetometry, time, navigation)
- communication technologies (random numbers, secure data)
- computation (QFT, chemistry, crypto-analysis, QMD)



- collaboration among academia, national labs, and industry is accelerating the pace of commercial development
- world-wide push

Gorshkov, ANL2018

Potential Contributions from **QIS and QC** to **Nuc. Phys. Simulation**



Scott Aaronson, Sci. Am.

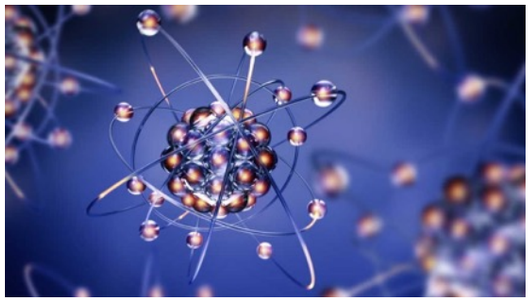
Quantum Computers can solve problems that classical ones cannot, but not expected to solve all problems

Nuclear Physics Problems

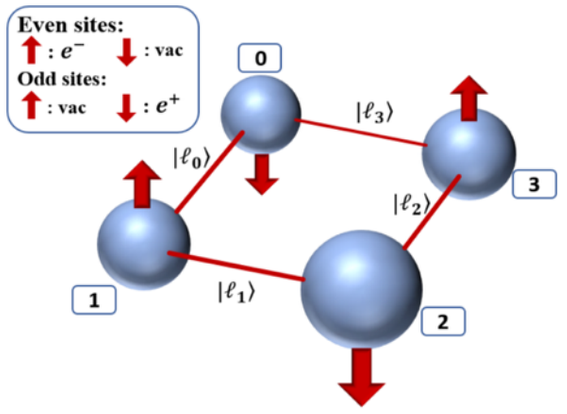
Real-time evolution and highly inelastic processes

Finite Density Systems
- some sign problems in quantum Monte Carlo

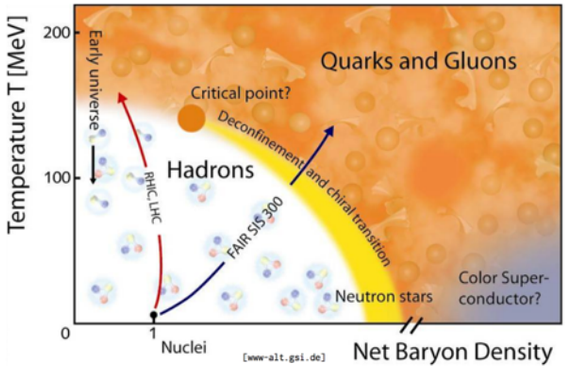
Potential Contributions from **QIS and QC** to **NP**
Simulation



The structure and interactions of medium and large nuclei directly from nuclear forces.
Exponentially large Hilbert spaces

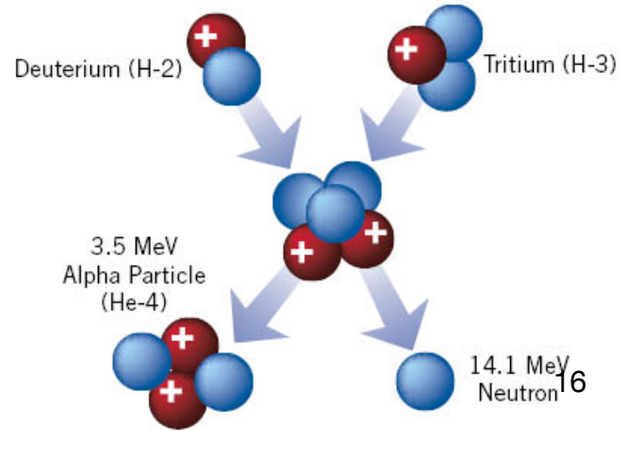


Lattice quantum field theories, QCD, EFT,…
Real-time dynamics, inelastic processes
Insights from model theories for NP-related physics

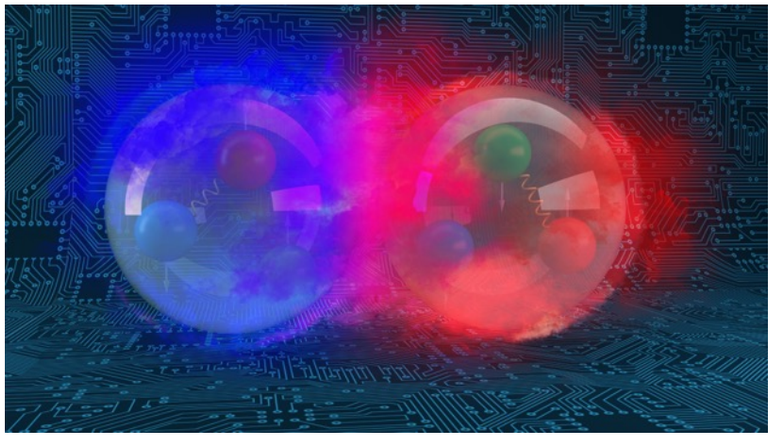


Equation of state of dense matter and neutron stars
The phase diagram of QCD
Conquering some “sign problems”

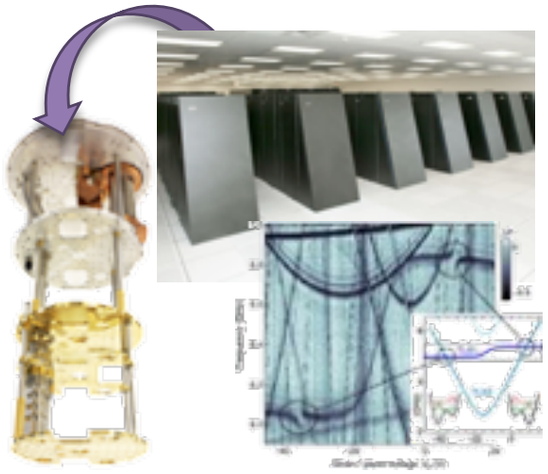
Electroweak processes in nucleons and nuclei
Dynamics of low-energy nuclear reactions and fission
Neutrino dynamics in astrophysical environments



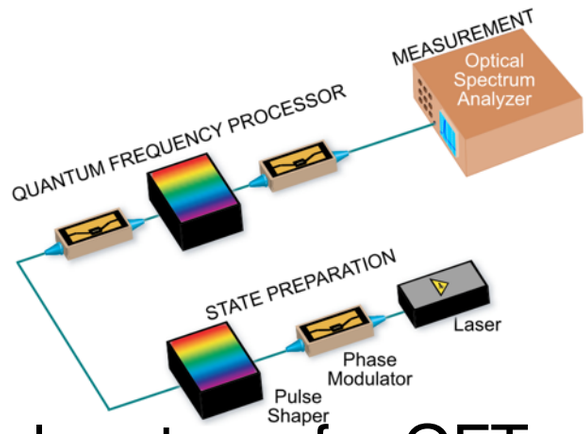
Potential Contributions from **QIS and QC** to **NP**
Early Simulations on quantum hardware



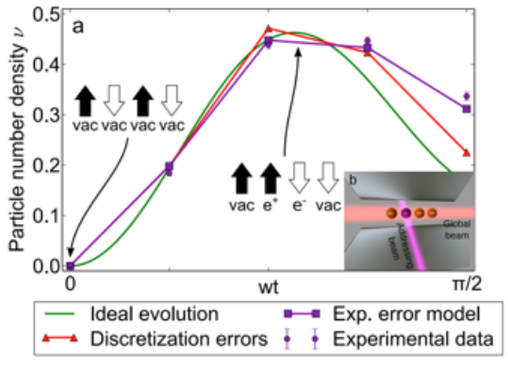
The deuteron
ORNL/UTK

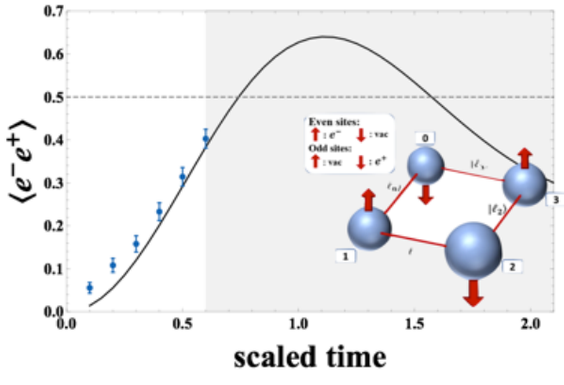


Qudits for low-energy nuclear reactions (LLNL)

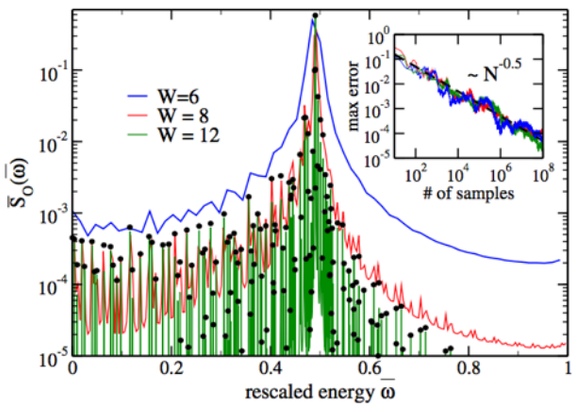


Optical systems for QFTs and nuclei
ORNL/UTK/Purdue/INT-UW

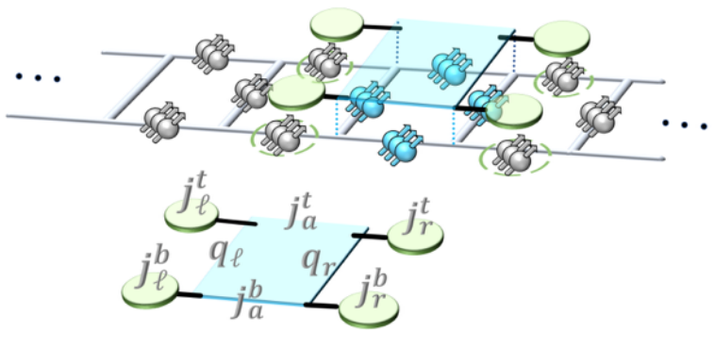




Schwinger Model on ions and IBM
Innesbruck and ORNL/INT-UW



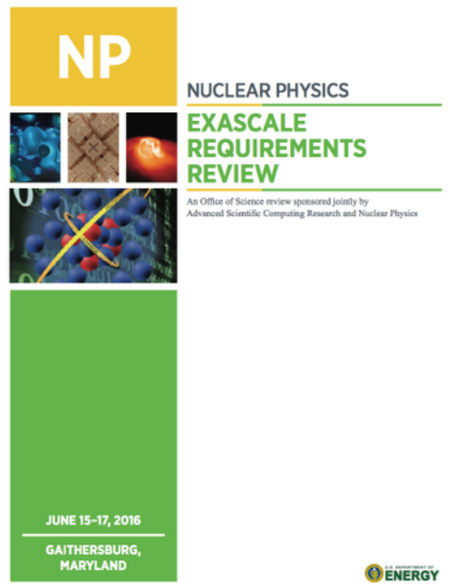
Nuclear Responses
LANL



Non-Abelian gauge field theory
INT-UW

Potential Contributions from **NP** to **QIS and QC**
Simulation

Expertise in quantum many-body systems and field theories, algorithms and HPC

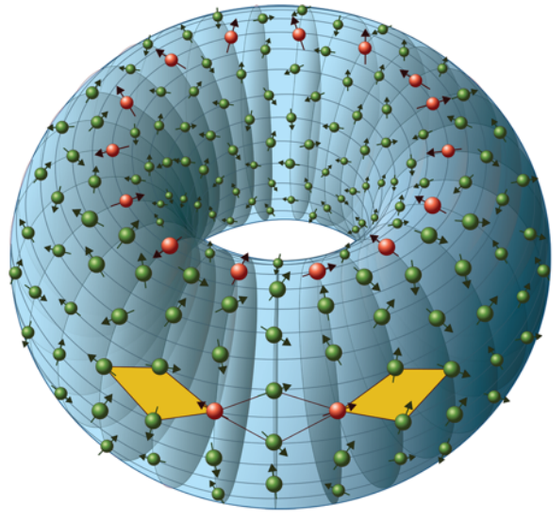


simulations of lattice quantum gauge theories and many-body systems
- short-range non-central and long range forces near RG fixed points

Physics-driven unique quantum algorithms
- different from HEP, BES, but synergistic

Non-relativistic systems emerge from and integrate with relativistic systems
- large range of length scales in heterogeneous systems

Design of logical qubits, quantum memory, and operating protocol
- nanotubes and topological insulators (domain-wall fermions)
- entanglement, information scrambling and de-localization in many-body systems



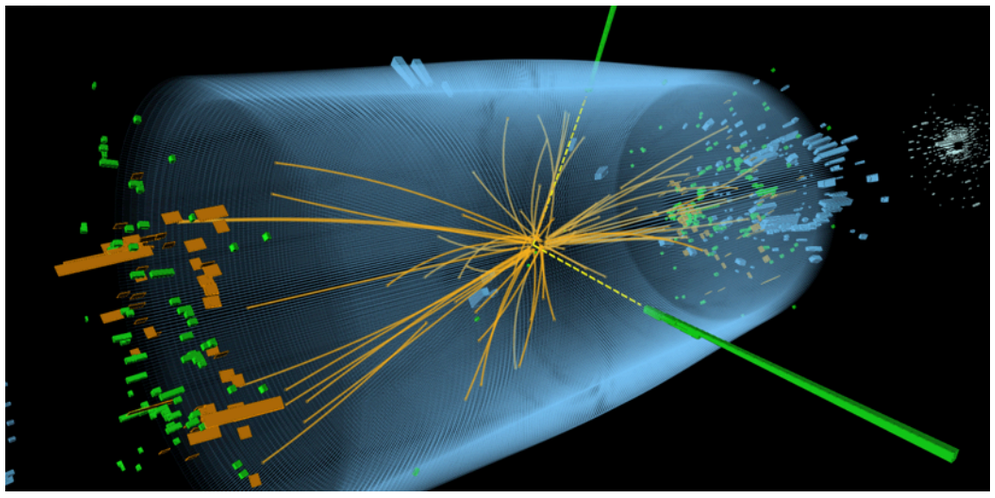
Design and requirements of future quantum hardware

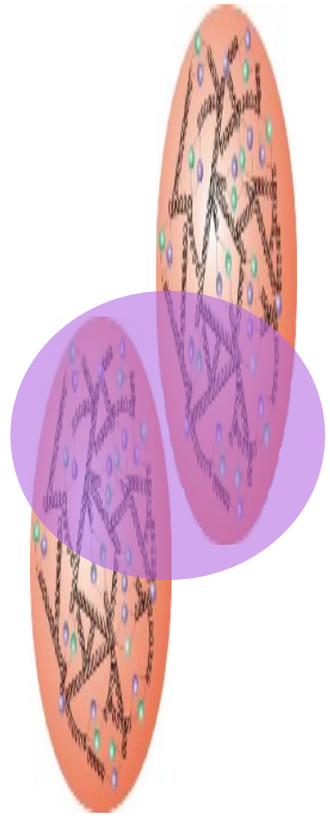
Sustained community-wide collaborations, including with HEP and ASCR

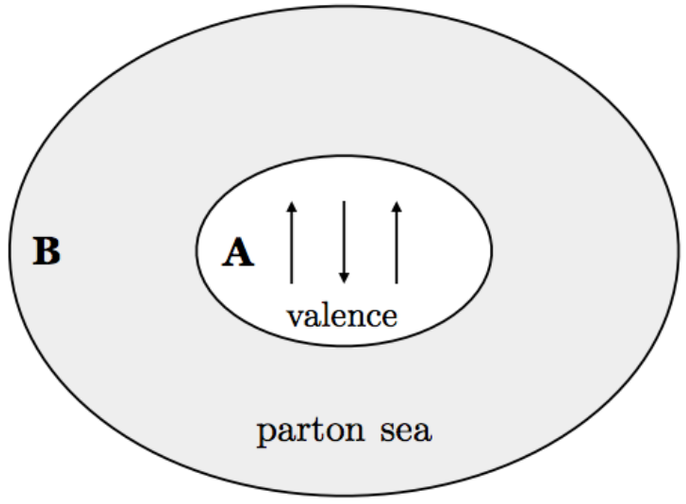
Potential Contributions from **NP** to **QIS and QC**

Entanglement

Exploring entanglement with NP experiments







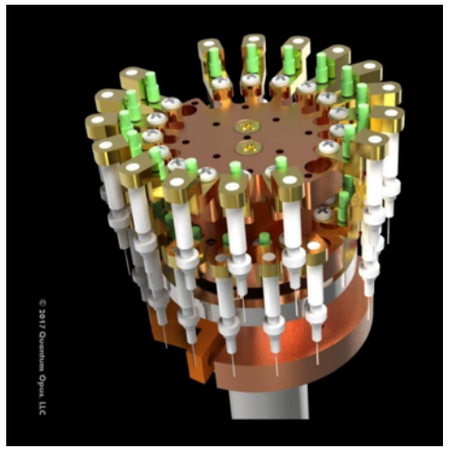
Emergent Symmetries
Spin-Flavor:
Wigner-Symmetry and SU(3)

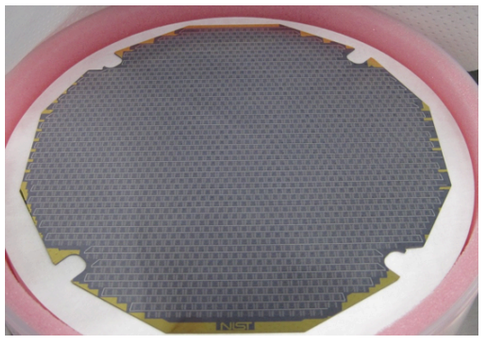
Vanishing Entanglement
Fluctuations by Nuclear
Forces - mean-field

known to eliminate sign problems in simulations

Potential Contributions from **QIS and QC** to **NP**

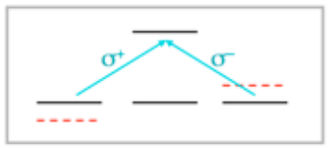
Sensors



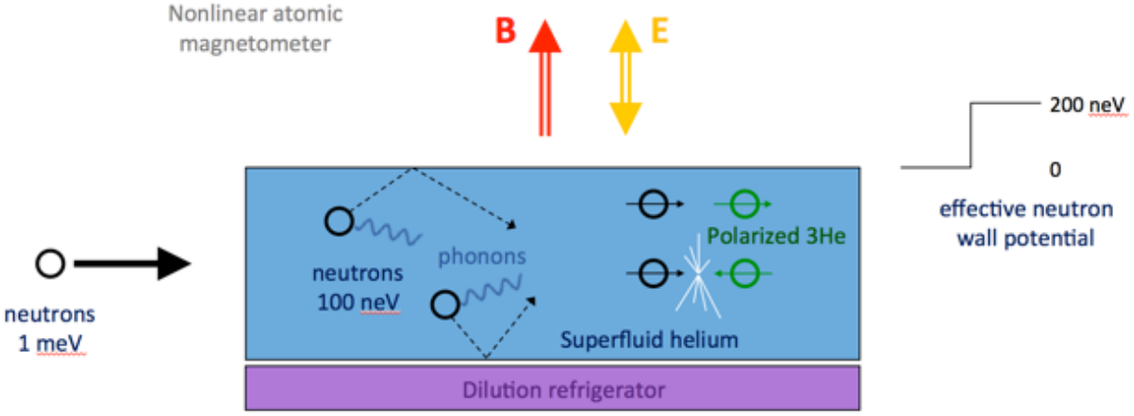


Advanced quantum 1.0 sensors continue to be broadly integrated into NP expt. programs.
e.g., SNSPDs, TESs, MKIDs, TWAs, …

Improved capability in sensing both the heat and light will improve sensitivity in the long-sought 0νββ-decay of nuclei in the search for lepton number violation.



Nonlinear atomic magnetometer

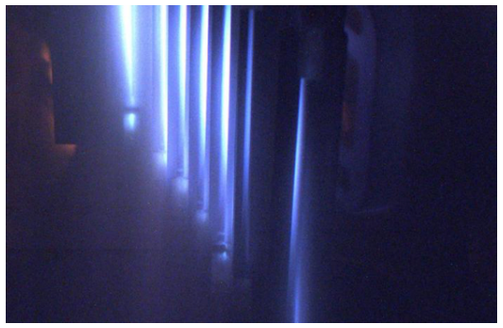


Quantum 2.0 sensors are nascent technologies.
Used in nEDM experiments to measure B-fields.

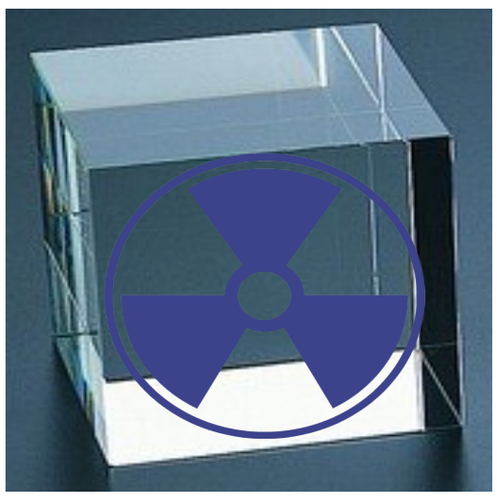
Expected to provide parametrically improved sensitivities in high-sensitivity experiments, searches for new physics, EDM, axions, 0νββ-decay.

Potential Contributions from **NP** to **QIS and QC**

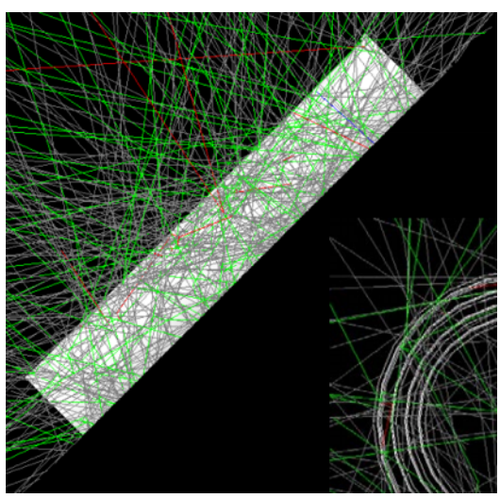
Sensors



Isotope enrichment and rare isotope development



Development of nuclear clocks using radioactive isotopes, e.g., ^{229}Th



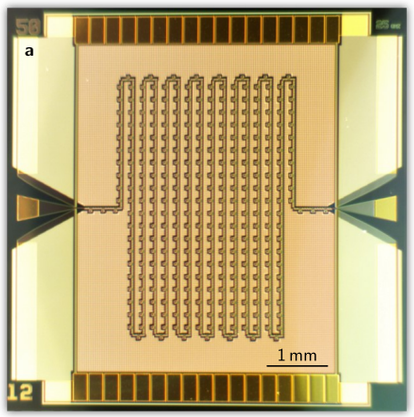
Understanding the impact of radioactive backgrounds on quantum devices

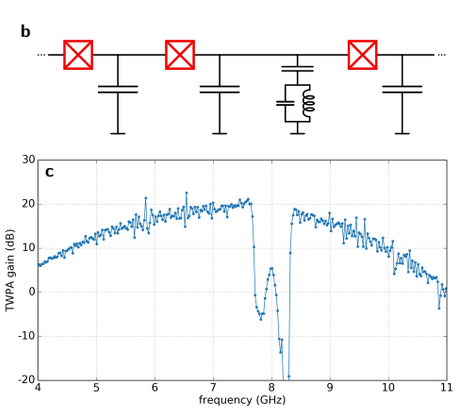
Potential Contributions from **NP** to **QIS and QC**

Sensors

Development of high complexity readout systems in highly sensitive and complex environments

Designing and developing new high-Q cavities for RF systems



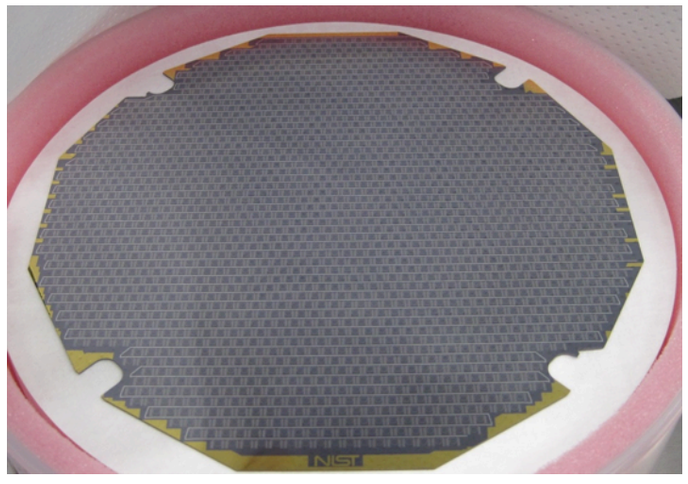


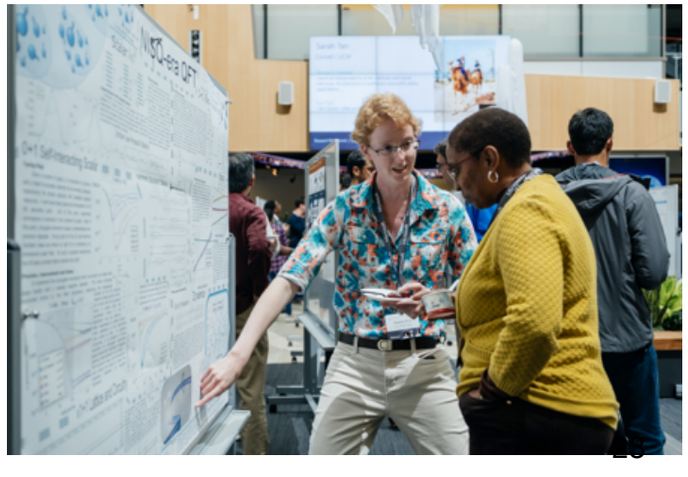
Josephson TWPAs
GHz SQUID amplifiers with 1 yoctowatt (10^{-24} W) range
Squeezing for photon detection - qubit technology

Synergies **NP - QIS/QC - ASCR - HEP - BES**

Boundary-free cooperation and coordination is KEY

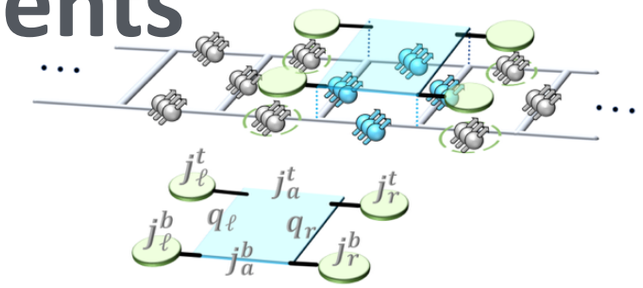
While distinct, there are significant synergies with AMO, ASCR, BES, CISE, HEP, QIS+QC in **Simulation**, **Sensors**, and in creating and sustaining a quantum-ready **Workforce** of scientists, engineers and developers.

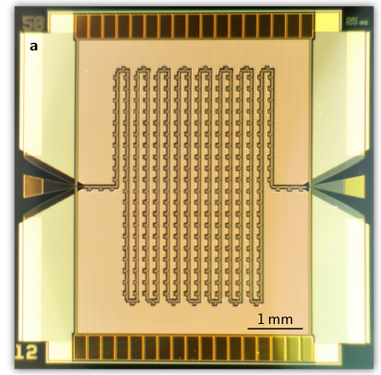




Path Forward for NP

A *Package* of Recommendations and Comments

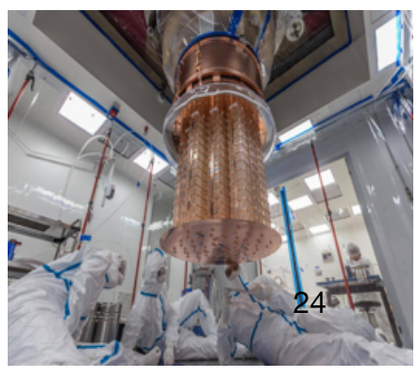




Recommendation 1A: Quantum Computing, Simulation, and Nuclear Physics

Recommendation 1B: Quantum Sensing in Nuclear Physics

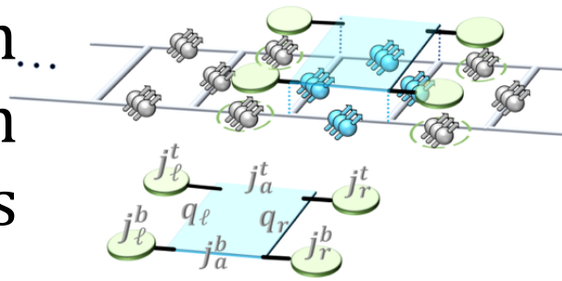
Recommendation 2: Exploratory Techniques and Technologies in Combined NP and QIS Activities

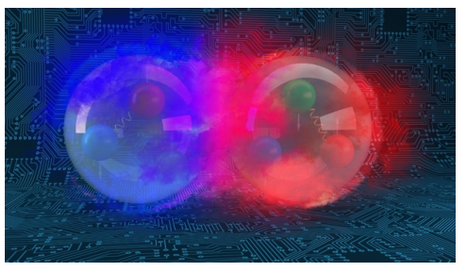


Recommendation 3: A Quantum-Ready Nuclear Physics Workforce

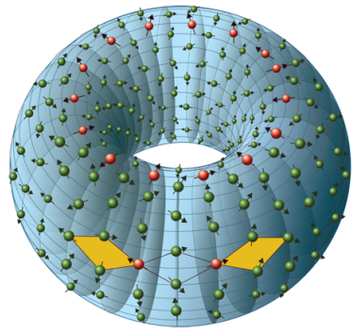
Rec. 1A: Quantum Computing, Simulation and NP

….. the intertwining of quantum device development, algorithm and application development, classical simulation of quantum devices, QC and simulation, and workforce development is essential in establishing a sustainable NP quantum ecosystem. ……

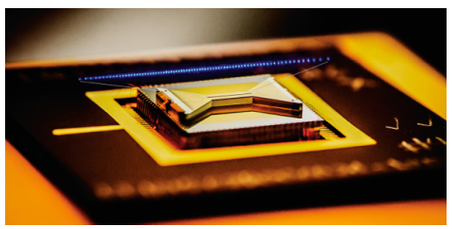




The NP quantum many-body and quantum field theory problems will help drive the development of QIS.

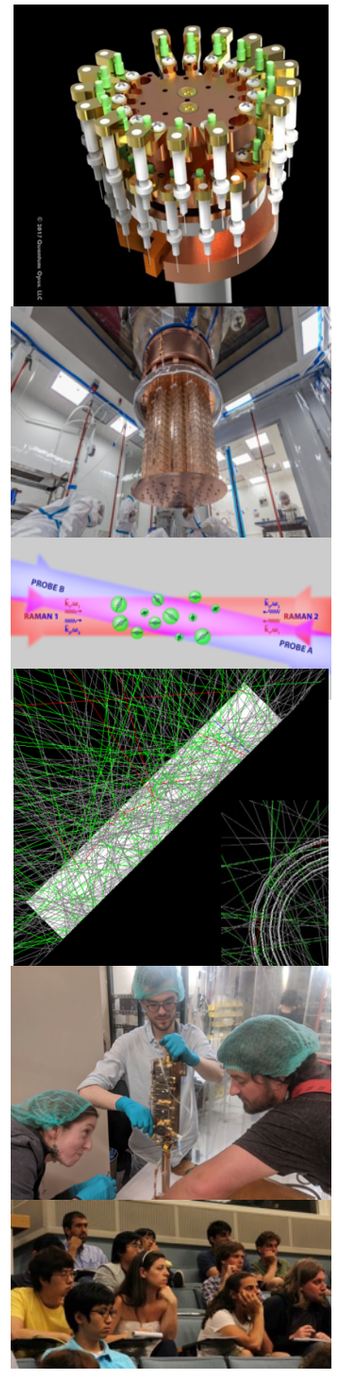


We recommend establishing one or more multi-institutional Quantum Co-Development Consortia for simulation. These Co-Development Consortia should pursue and facilitate the development of quantum simulation capabilities for NP research and utilize NP expertise in quantum many-body physics and quantum field theory to impact quantum information science and quantum computing.



Rec. 1B: Quantum Sensing in NP

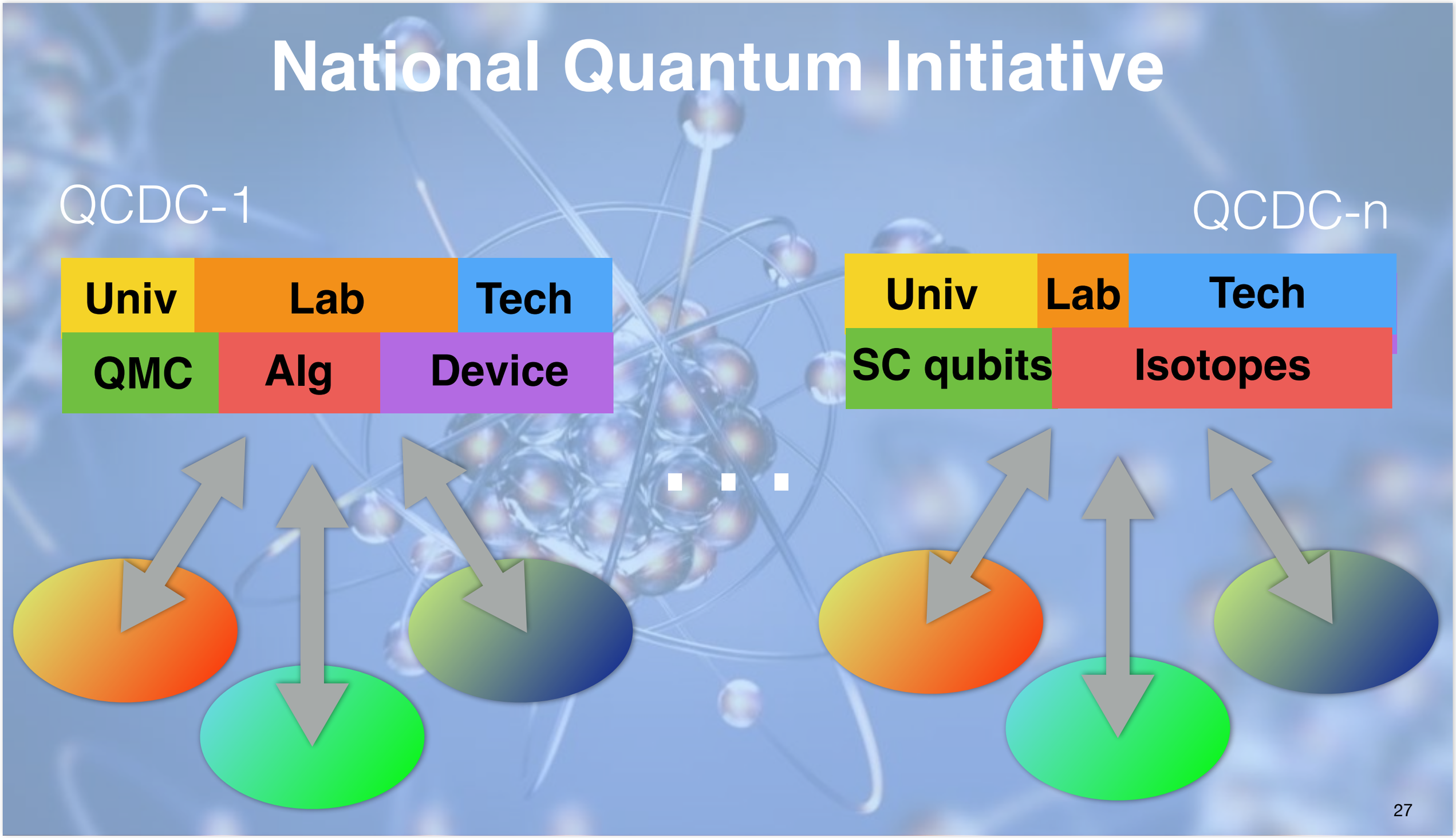
Expertise within the NP community provides opportunities to drive forward the development of quantum sensors and other quantum devices.



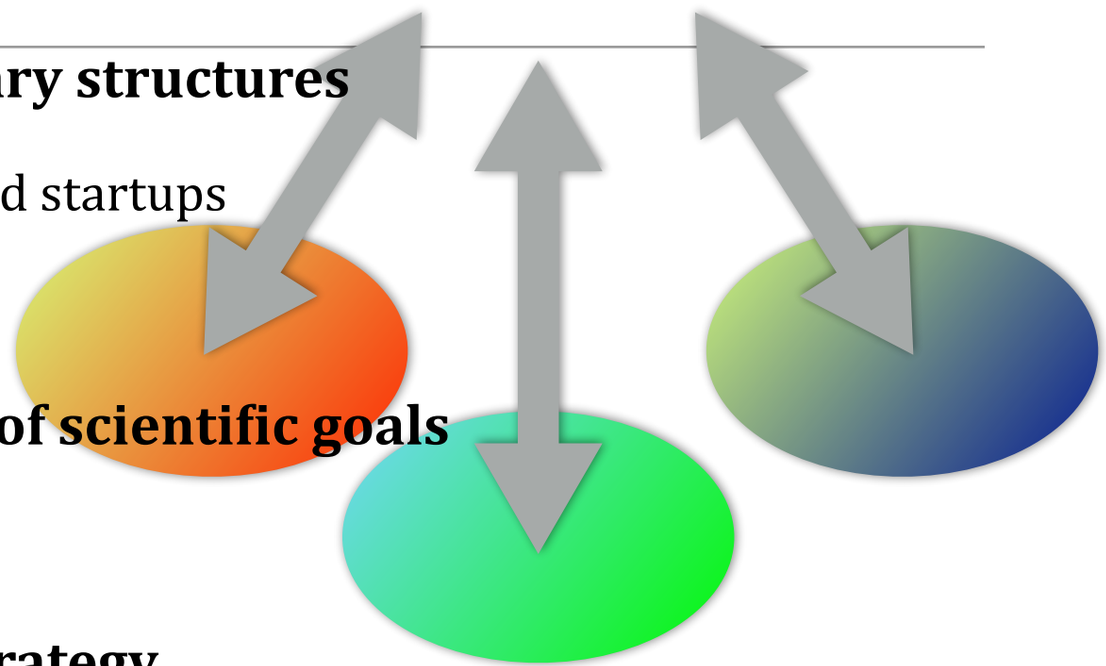
…. Quantum sensors are expected to enable transformative changes in the design of high-priority NP experiments. ….

We recommend establishing one or more multi-institutional Quantum Co-Development Consortia for sensors focused on targeted, prioritized, cross-disciplinary developments in quantum-enhanced sensing for NP research.

QCDC - Quantum Co-Development Consortia



Comment 1: QCDC - Attributes



- **"light-weight" multi-institutional and multidisciplinary structures**
  - well-defined mission statements
  - bring together national labs, universities, tech companies and startups
  - approximately 5 years to become firmly established
  - support only while ***accelerating*** advances in QIS or QC
- **organization and structure to optimize achievement of scientific goals**
  - support the activities of their members
  - synergies with ASCR, BES, HEP and QIS
- **identify research and engagement priorities and a strategy**
  - able to dynamically respond
- **workshops, workforce training, mid- and long-term visiting arrangements**
- **enable researchers to carry out small-to-medium-scale explorations**
  - larger, production-scale activities.
- **the best parts of established models**
  - SciDAC projects, mid-scale experimental collaborations, NSF Physics Frontiers Centers, and DOE theory Topical Collaborations
- **a portal to communicate and engage with scientists, engineers and developers, NQI, agencies**
- **close collaborative relationship among the QCDC and anticipated NQI Centers**

Rec. 2: Exploratory Techniques and Technologies in combined NP and QIS Activities

… at the small scale, support for nascent new techniques and technologies in this domain should enable rapid and flexible NP response to newly apparent opportunities …

We recommend that DOE and NSF encourage and support selected exploratory technologies and techniques that have promise to be of mutual benefit to NP and QIS or QC research activities.

- experiment, HPC, theory
- independent stand-alone projects critical to the success of QCDCs and NP growth in QIS
- should enable rapid and flexible NP response to new opportunities
- provide intellectual and training support for the overall NP effort
- high-stakes, high-payoff research

Rec. 3: Quantum-Ready NP Workforce

With the expectation of mutual benefit, we recommend strengthening the QIS and QC expertise in the NP workforce.

- a quantum-ready workforce is essential to the ecosystem supporting the emerging quantum economy
- includes NP scientists, engineers and developers
- broad engagement of NP with other domains is required
- in-person creative gatherings are essential - translations of languages are required
- co-advising
  - CS researchers now need to know physics and vice versa

NP could develop this workforce with activities including the following:

- Annual summer schools and training programs
- Annual conferences
- Graduate fellowships
- Recruit postdoctoral fellows with expertise in QIS
- Bridge positions - scientists, engineers, developers, …
- Visiting scholar positions
- Enlarge the scope of the SciDAC program, or establish analogous programs

Workforce Development - Construction ...
constructioncareercollaborative.org

Comment 2: Suggestions to the NP Community

In addition to previous suggestions :

- Journals encouraged to broaden scope to work describing QIS, QC for NP research.
- NP encouraged to engage with technology companies and startups.
  - attention to intellectual property will be required.
- NP course offerings to include QIS and QC
- **Regularly evaluate the progress of QIS and QC efforts**

Comments: 3 and 4

Future-Proofing QC and Simulations

- Technology companies and startups developing hardware and software for QC - and access!
- DOE ASCR, and NSF are establishing quantum test beds
- Rapid evolution expected

- **NP will benefit from connections with tech companies and startups**
  - **risk to the NP scientific mission in relying on them to provide sustained access and high-quality support.**

- Consider similar infrastructure for quantum resources to that established for HPC
  - QC hardware and open-source software and tools
  - complement those from ASCR and NSF computing

Developing the Quantum-Ready Workforce

- Quantum mechanics related to QIS and QC accessible to a broad audience
- QED-C/NIST - engagement with broader ecosystem
- NSF Triplets program

... The fields of QIS and QC are in many ways defined by new thinking. It is difficult to overstate the importance of bringing young people into the field to create and explore the new ideas that will be required. At the same time, we must take care to ensure this workforce development sequence is whole, from educating undergraduates, to nurturing young professionals and researchers, to establishing fulfilling permanent positions....

Acknowledgements

Speakers

Readers

Steven Girvin (Yale University)
Shanalyn Kemme (Sandia National Laboratory)
Raymond LaFlamme (University of Waterloo)
Joseph Lykken (Fermi National Accelerator Laboratory)
Christopher Monroe (University of Maryland and IonQ)
Joel Moore (University of California, Berkeley)
Krysta Svore (Microsoft)
Joel Ullom (University of Colorado and National Institute for Standards and Technology)
Steven Vigdor (Indiana University).

Adminstrative

Ida Boeckstiegel (Center for Experimental Nuclear Physics and Astrophysics, University of Washington)
Gary Holman (Center for Experimental Nuclear Physics and Astrophysics, University of Washington)
Christine Izzo (US Department of Energy)
Brenda May (US Department of Energy)
Linda Severs (Oak Ridge National Laboratory)
Brenda Wyatt (Oak Ridge National Laboratory)

Summary

Nuclear Physics can *benefit from* and *uniquely contribute to* advances in Quantum Information Science and Quantum Computing in multiple ways.

Charges to NSAC and QIS Subcommittee

U.S. Department of Energy
and the
National Science Foundation

October 29, 2018

Professor David Hertzog
Chair
DOE/NSF Nuclear Science Advisory Committee
Department of Physics
University of Washington
Seattle, Washington 98195

Dear Professor Hertzog:

This letter requests that the Department of Energy (DOE)/National Science Foundation (NSF) Nuclear Science Advisory Committee (NSAC) conduct a study to identify unique opportunities for U.S. nuclear physics research to contribute to advances in Quantum Computing and Quantum Information Science (QIS). In carrying out this study, NSAC should provide information assessing the relative importance and potential benefits of QIS to nuclear physics and the potential contributions that nuclear physics can make to QIS.

QIS research is playing an increasingly central role in the vision for the future of U.S. science and technology. Emerging QIS priority areas provide promising new avenues for addressing challenges of enormous complexity, including, for example dramatic extensions of the application of Quantum Field Theory to the analysis of physical systems at scale with heretofore intractably large numbers of degrees of freedom that cannot be addressed by conventional computing. In another area of rapid development, quantum entanglement in multi-particle states is opening new horizons in quantum sensing, quantum communication, quantum computing, and quantum simulations.

Decades of accumulated intellectual capital, extensive experience in interdisciplinary research, considerable technical infrastructure at labs and universities, and a long history of international leadership in collaborative research have positioned the DOE Office of Nuclear Physics and the NSF nuclear physics research programs to engage in QIS relevant research. However, QIS is newly emergent as a priority area for Research & Development (R&D) investment in nuclear science. Furthermore, private sector R&D investment in QIS, as well as investment by other Federal agencies, has been ongoing for some time. NSAC is therefore requested, in the context of Federal and private sector research efforts already underway, to articulate the unique role nuclear science research, aligned with the DOE and NSF nuclear physics programs, can and should play in Quantum Information Science. While unique, this role should nevertheless align broadly with the goals outlined in the national strategy for QIS[1].

[1] https://www.whitehouse.gov/wp-content/uploads/2018/09/National-Strategic-Overview-for-Quantum-Information-Science.pdf

Please submit your report to DOE and NSF by summer of 2019. The agencies very much appreciate NSAC's willingness to undertake this task and anticipate that the information provided in this report will be important in guiding DOE and NSF nuclear physics investments in this newly emergent area for Federal R&D.

Sincerely,

J. Stephen Binkley
Deputy Director for Science Programs

Anne L. Kinney
Assistant Director, Directorate for

DEPARTMENT OF PHYSICS
UNIVERSITY of WASHINGTON
College of Arts & Sciences

Box 351560
Seattle, WA 98195

Tel: 206-543-1493

January 9, 2019

Professor Martin Savage
Institute of Nuclear Theory
University of Washington

Dear Martin,

J. Stephen Binkley, Deputy Director for Science Programs at the Department of Energy, and Anne L. Kinney, Assistant Director of Mathematical and Physical Sciences at the National Science Foundation, have requested that NSAC form a Subcommittee to identify unique opportunities for the U.S. nuclear physics research community to contribute to advances in Quantum Computing (QC) and Quantum Information Science (QIS) and to identify potential benefits of QIS and QC to Nuclear Physics. Their charge letter is attached.

I am writing to formally ask you to serve as the Chair of this new NSAC Subcommittee, and to help me establish a broad and diverse membership having a collective expertise across a wide range of QIS and QC subjects. As you are well aware, Quantum Information Science – broadly defined – is now a high-priority, multi-disciplinary initiative within the U.S. science and technology community at large. Significant funding opportunities have been enabled by recent legislation with the aim to widely distribute support to different specialty areas. In that context, your committee should develop guidance as to how the Nuclear Science community can most effectively contribute to the advancement of QIS; for example, one anticipates topics ranging from quantum computing for science applications to development of sensitive quantum sensors. These are areas for which U.S. nuclear scientists are already beginning to make valuable contributions. Your committee will likely need to host one or more information meetings with the aim of acquiring expert input and advice that will be folded into your report. To be most useful, NSAC would appreciate receiving your report by early Summer 2019.

I realize this is a heavy responsibility and a burden on your time and that of the Subcommittee. I, and our whole community, will owe you an enormous debt of gratitude.

Sincerely yours,

David W Hertzog,
Chair NSAC

FIN

Supporting Material

QED-C Technical Advisory Council Sub-Committees

- **Workforce** – Leader: Jason Turner, Entanglement Institute. Quantum workforce shortfall, data, solutions, USG R&D impact, Assess Resources Required
- **Enabling Technologies** – Leader: Thomas Ohki, Raytheon BBN. Identify gaps, Categorize, Prioritize, Identify needed R&D, Supply Chain, Assess Required Resources
- **Quantum Use Cases** – Leader: Jim Gable, Bra-Ket Sciences. Define the "Killer Quantum Apps", Markets, Timeline, Roadblocks, CONOPS, CSWaP, R&D Required
- **Standards and Performance Metrics** – Leader: Tom Lubinski, Quantum Circuits, Inc. Types of Stds. and KPI's, Organization(s) and Structures