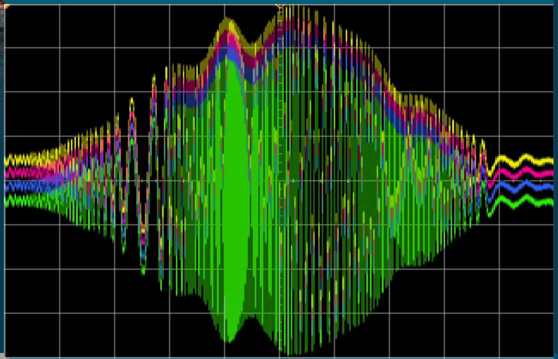
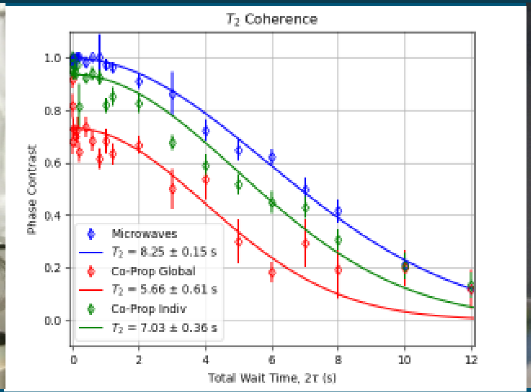
SAND2021-15211C

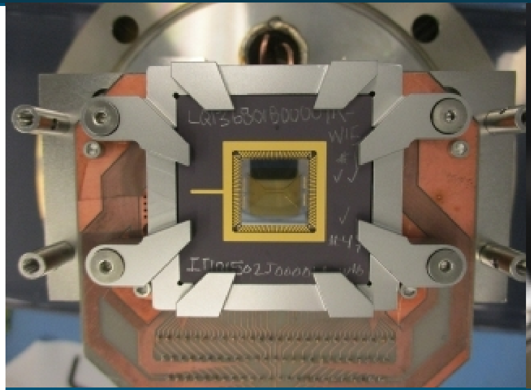
Sandia National Laboratories

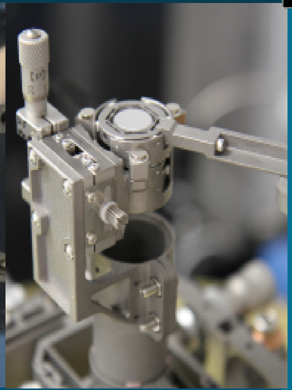
QSCOUT: A “White-Box” Quantum Testbed Based on Trapped Ions at Sandia National Laboratories



QSCOUT







U.S. DEPARTMENT OF ENERGY

Office of Science

PRESENTED BY

Susan Clark and the QSCOUT team

U.S. DEPARTMENT OF ENERGY NNSA

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Need quantum hardware accessible to as many people as possible
3 Tiers of accessibility:

Industry

Works at maximum efficiency but more difficult to study how machine works

IONQ

rigetti

IBM

Honeywell

Open Quantum Testbeds

Versatile and configurable, but less optimized for performance

QSCOUT

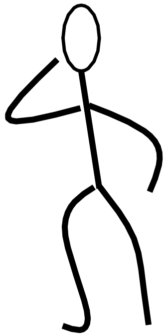
Sandia National Laboratories

AQT

BERKELEY LAB

Build your own

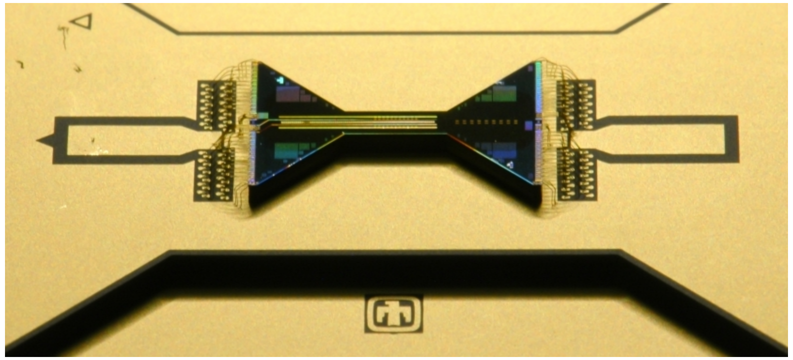
Total control, but expensive and difficult to build



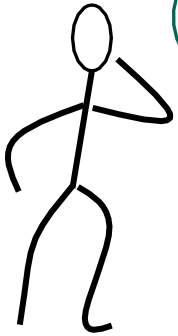
Low-level control →

← Ease of access

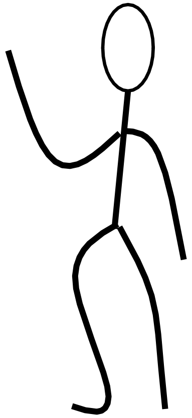
Building a system for users brings new requirements and a need to set ourselves apart from industry



What questions do they want to answer that they can't with existing systems?



Low-Level Access is the key!



QSCOUT goals:

- Greater understanding of how quantum machines work (and fail)
- Study new techniques for encoding and compiling quantum circuits
- Construct a roadmap for building larger, more sophisticated machines

First we needed basic capabilities: 5 major upgrades

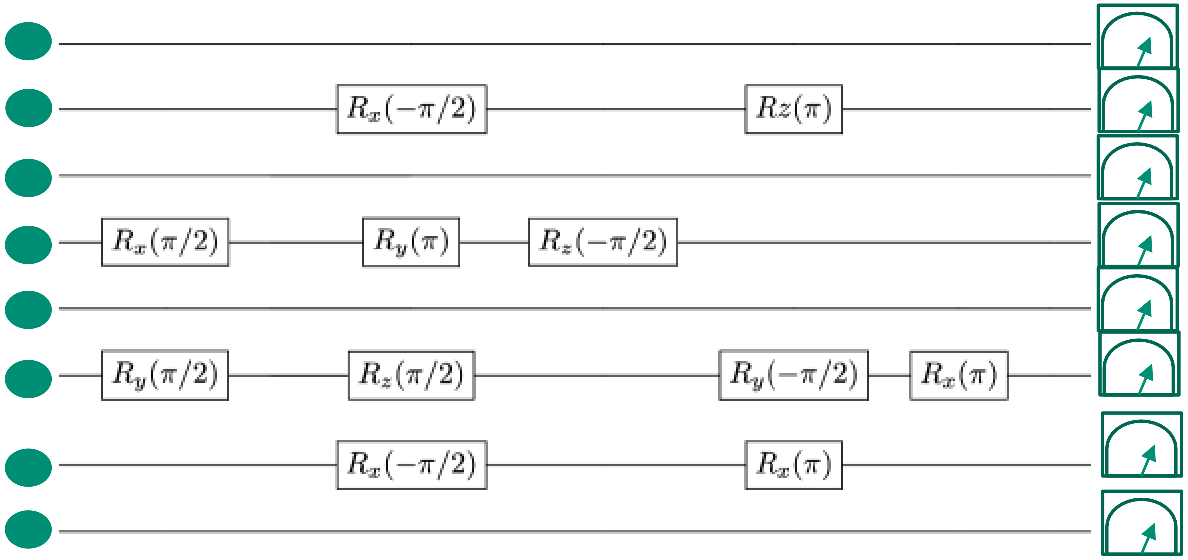
QSCOUT

JAQAL

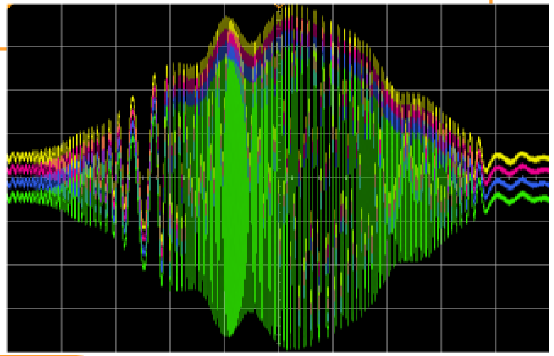
Multiple ion techniques

Individually address ions or pairs of ions

A quantum assembly language to specify gates



New hardware for advanced pulse/gate generation



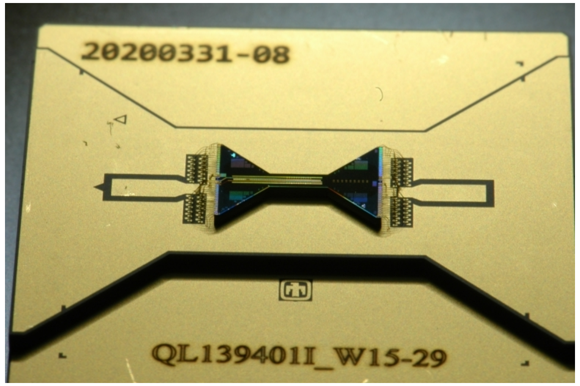
Distinguishable detection of each ion (*which* ion is in 1 or 0)

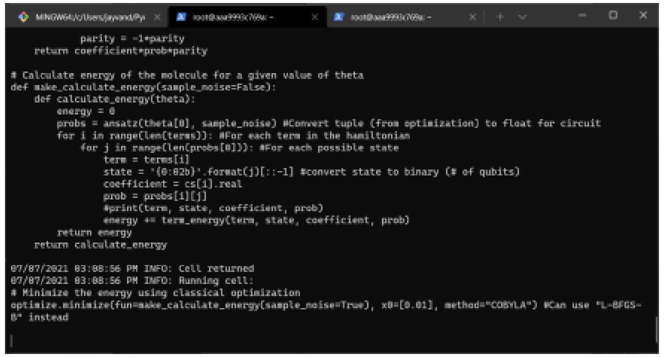
"Engineering QSCOUT, design details and user guide." Susan Clark et al. https://arxiv.org/abs/2104.00759

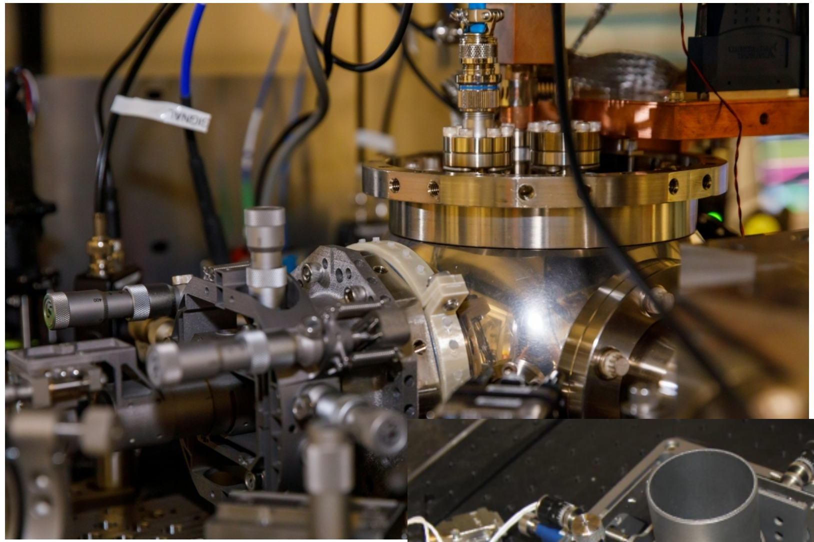
Quantum systems engineering requires a diverse skill set

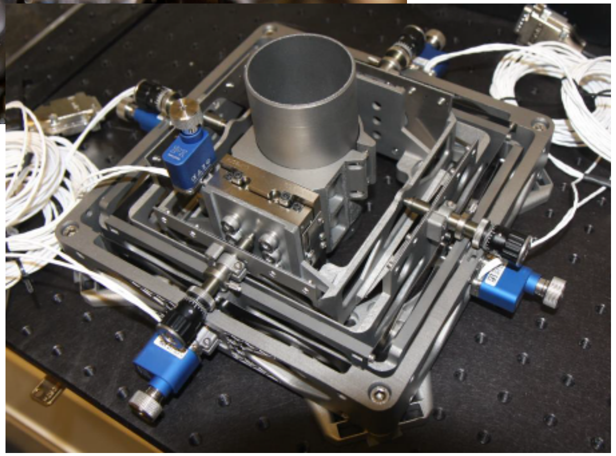
Complete quantum systems development requires:

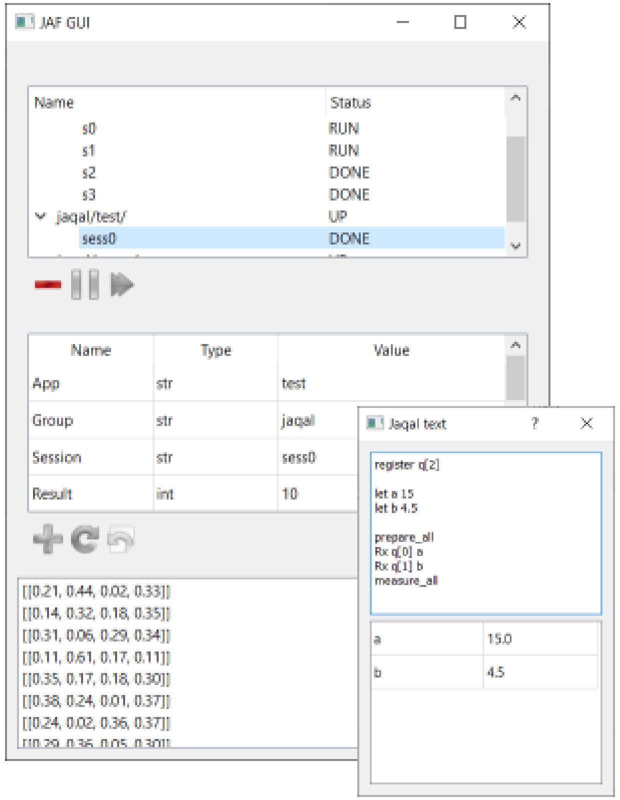
- Physicists
- Fabrication specialists
- RF electronics engineers
- Electrical engineers
- Materials scientists
- Mechanical engineers
- Optical engineers
- Software engineers
- And more!











A new quantum programming language for flexibility and control: Jaqal

Jaqal

JAQAL

The quantum part

```
register q[2]

prepare_all
hadamard q[0]
cnot q[1] q[0]
measure_all
```

JaqalPaq: https://gitlab.com/jaqal/jaqalpaq

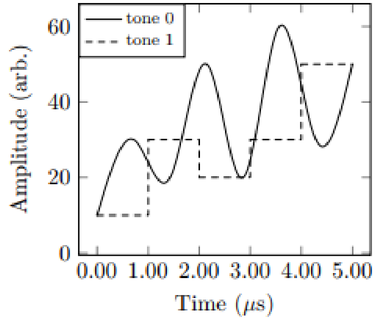
Meta programming with python, emulator, transpiliers

```
JaqalCircuitObject = parse_jaqal_file("jaqal/Sxx_circuit.jaqal")
JaqalCircuitResults = run_jaqal_circuit(JaqalCircuitObject)
print(f"Probabilities: {JaqalCircuitResults.subcircuits[0].probabil
JaqalProgram = generate_jaqal_program(JaqalCircuitObject)
```

JaqalPaw

Pulse level control

```
def gate_G(self, qubit):
    spline_amps = (10,30,20,50,20,60,30,50)
    discrete_amps = [10,30,20,30,50]
    return [PulseData(qubit,
                      5e-6,
                      freq0=200e6,
                      freq1=230e6,
                      amp0=spline_amps,
                      amp1=discrete_amps)]
```



There are many programming languages out there. Why Jaqal for QSCOUT?

- **Transparency:** Fully specify native gates
- **Schedulability:** Full control of sequential and parallel execution of quantum gates
- **Extensibility:** Pulse level control of laser gates (intimately tied to hardware)

B. C. A. Morrison, *et al.*, “Just Another Quantum Assembly Language (Jaqal),” *2020 IEEE International Conference on Quantum Computing and Engineering (QCE)*, 402-408 (202

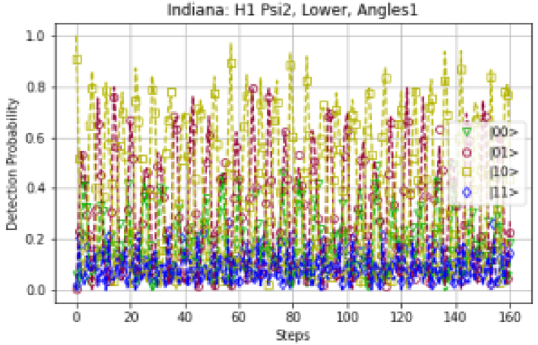
How have users interacted with low-level access?

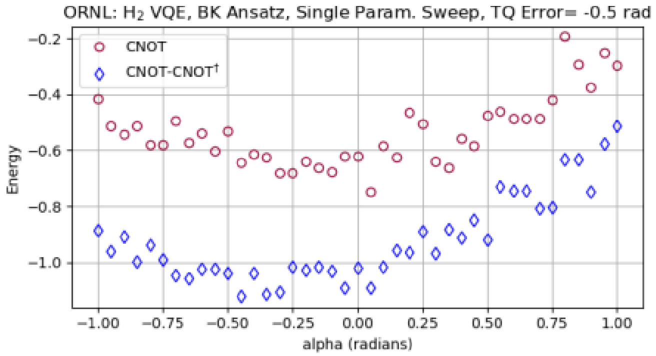
QSCOUT

- We offer single qubit rotations about any axis of any angle
- We offer “small-angle” two-qubit gates, which have higher performance than CNOTs

INDIANA UNIVERSITY BLOOMINGTON

Used composite CNOT gates, which were added to our calibration routine.

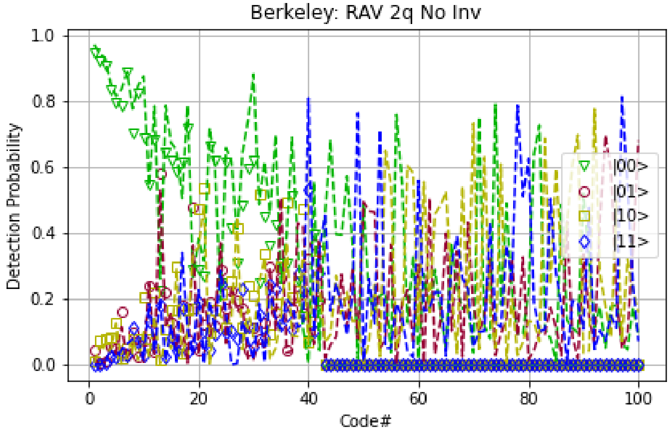




OAK RIDGE National Laboratory

We were able to purposefully introduce noise and miscalibration to test robustness

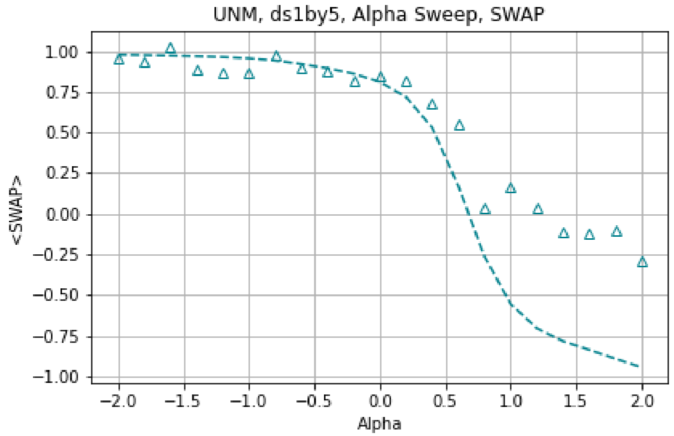
THE UNIVERSITY OF NEW MEXICO



Berkeley UNIVERSITY OF CALIFORNIA

Analog benchmarking > 1000 unique gates (axes and angles)

Used variable “small-angle” gates to test different amounts of Trotterization



Round 2 is underway!

Collaboration works both ways!

- Requests from users allowed us to rethink some calibrations and overall make the system better
- Requests from users show us new ways to break the system!

Round 2

JOHNS HOPKINS APPLIED PHYSICS LABORATORY

IBM

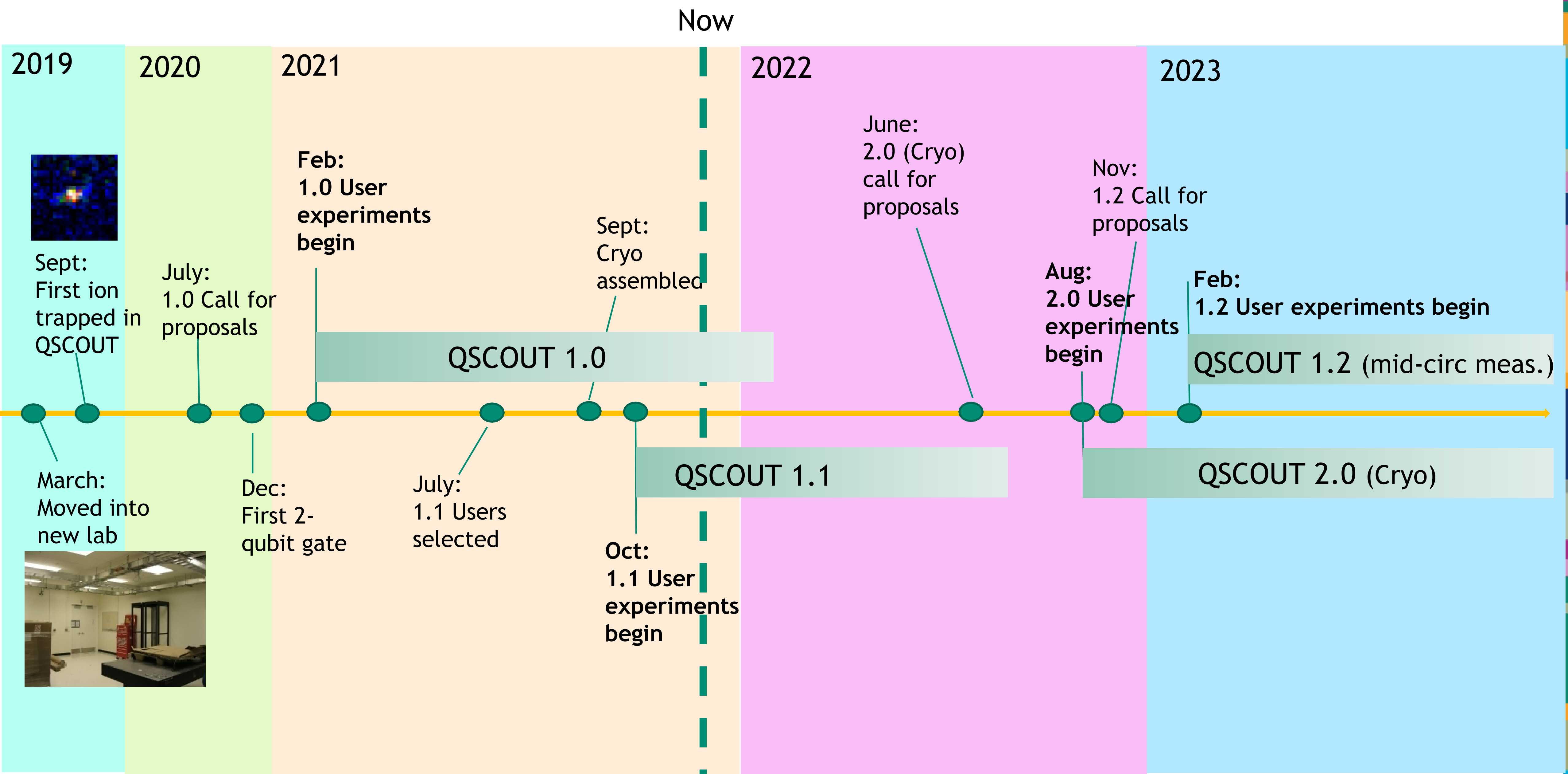
SUPER.TECH

LCN LONDON CENTRE FOR NANOTECHNOLOGY

Lawrence Livermore National Laboratory
SCIENCE & TECHNOLOGY ON A MISSION

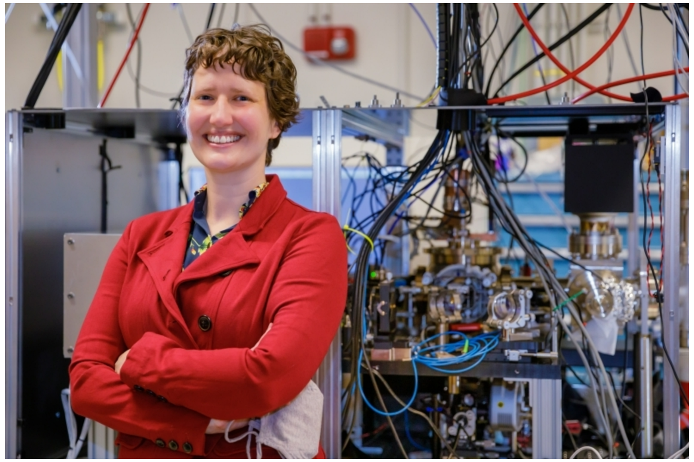
INDIANA UNIVERSITY BLOOMINGTON

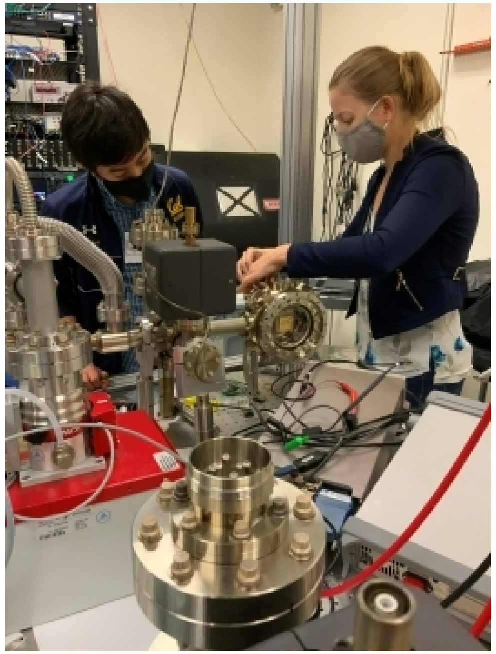
QSCOUT Timeline



Getting involved, more information

Email: qscout@sandia.gov to be added to mailing list
Website: https://qscout.sandia.gov
Jaqal: https://gitlab.com/jaqal/jaqalpaq





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