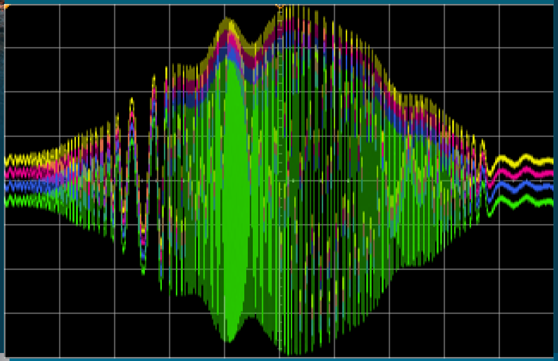
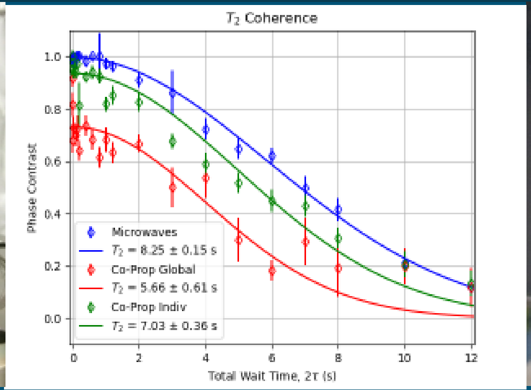
SAND2021-8485C

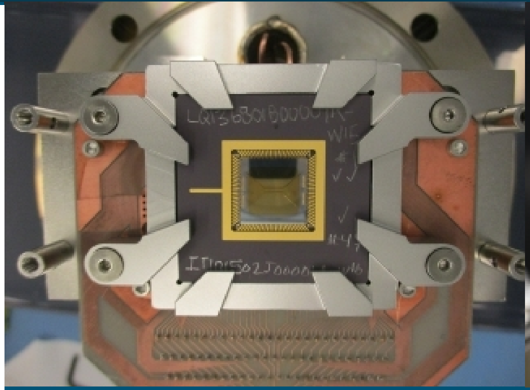
Sandia National Laboratories

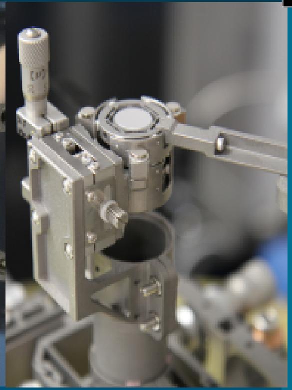


QSCOUT

Quantum Hardware for All







U.S. DEPARTMENT OF ENERGY
Office of Science

PRESENTED BY

Susan Clark

U.S. DEPARTMENT OF ENERGY NNSA

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Women are particularly good for quantum research

QSCOUT

The best people from 100 % of the population are better than the best people from 50 % of the population

Action items:

- Support each other
- Support programs for underrepresented groups
- Get your face out there
- Diverse hiring committees

Personally: Quantum Mechanics was a level playing field

no one started with intuition

Sandia National Labs is a US Department of Energy Laboratory with many diverse projects

QSCOUT

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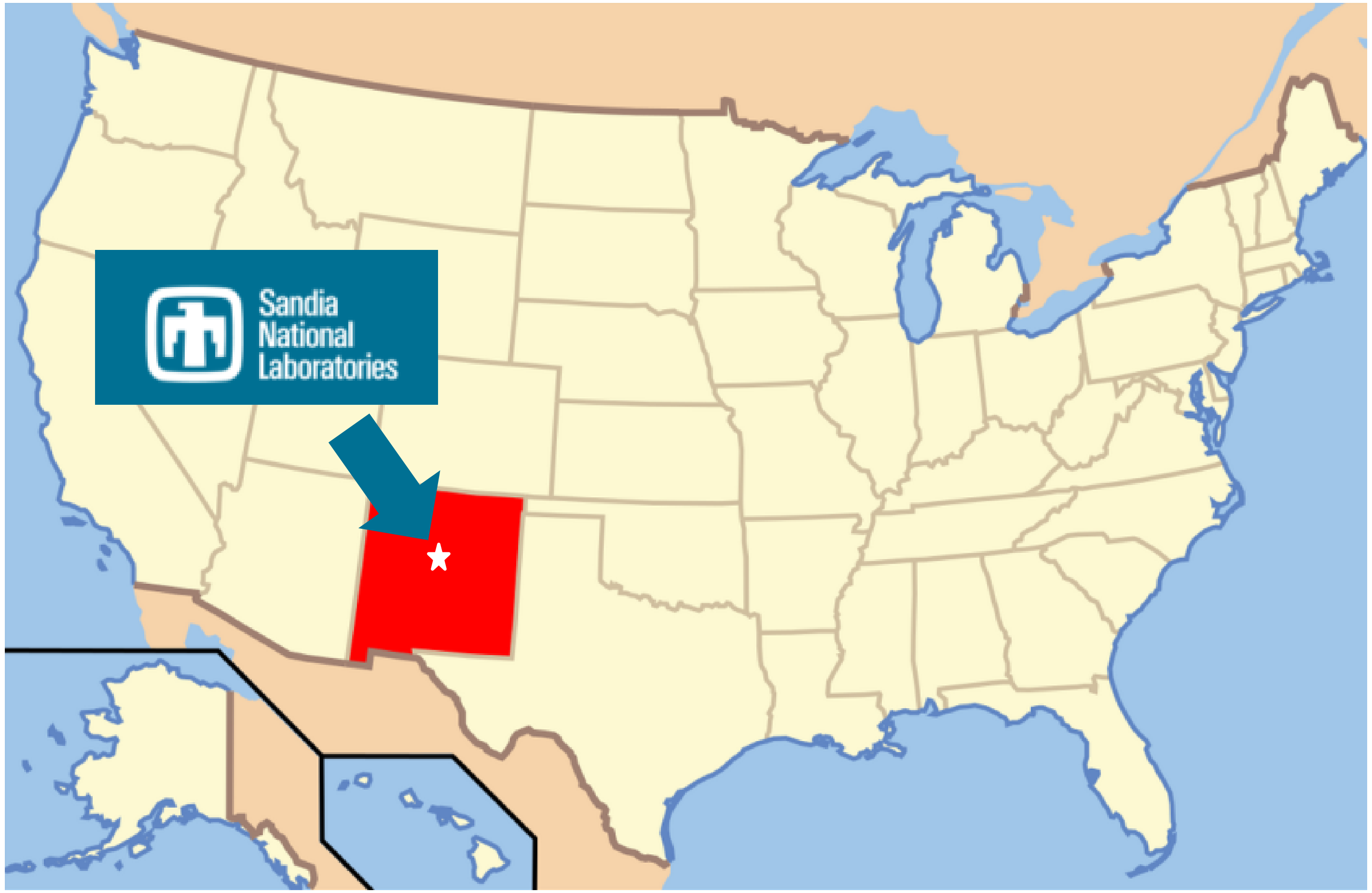
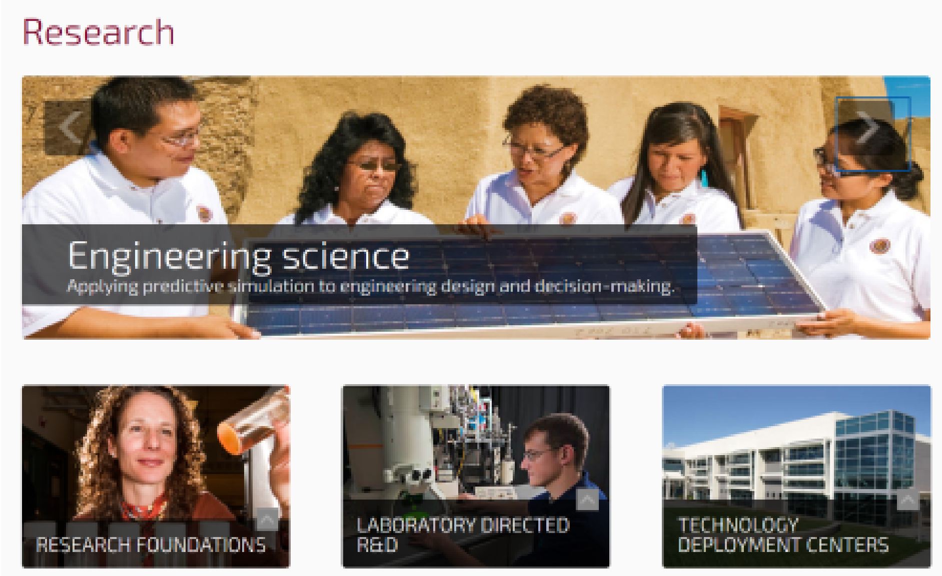


https://www.sandia.gov/



Quantum computing is a worthy field of study, still many unknowns!

QSCOUT

Quantum computers solve problems intractable on classical computers with as few as 50 qubits: (200 seconds vs. 10,000 years)

"Quantum supremacy using a programmable superconducting processor." Arute, F. et al. *Nature*. 2019.

"Quantum computational advantage using photons." Zhong, H.-S. et al. *Science*. 2020.

Exact resources needed for solving ***useful*** problems still unknown

Quantum chemistry, physics, material science, factoring, unstructured search

"Quantum simulation of chemistry with sublinear scaling in basis size." Babbush, R. et al. *NPJ: Quantum Information*. 2019.

And references therein

Best way to ***build*** and ***use*** a quantum computer still an open question

Need everyone to contribute!

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

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

IONQ

rigetti

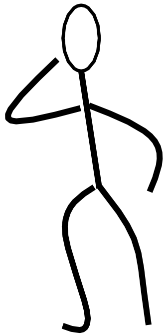
IBM

Honeywell

Versatile and configurable, but less optimized for performance

QSCOUT

Total control, but expensive and difficult to build



Build your own

Low-level control →

← Ease of access

For running useful circuits, needed to bring 5 major capabilities to Sandia

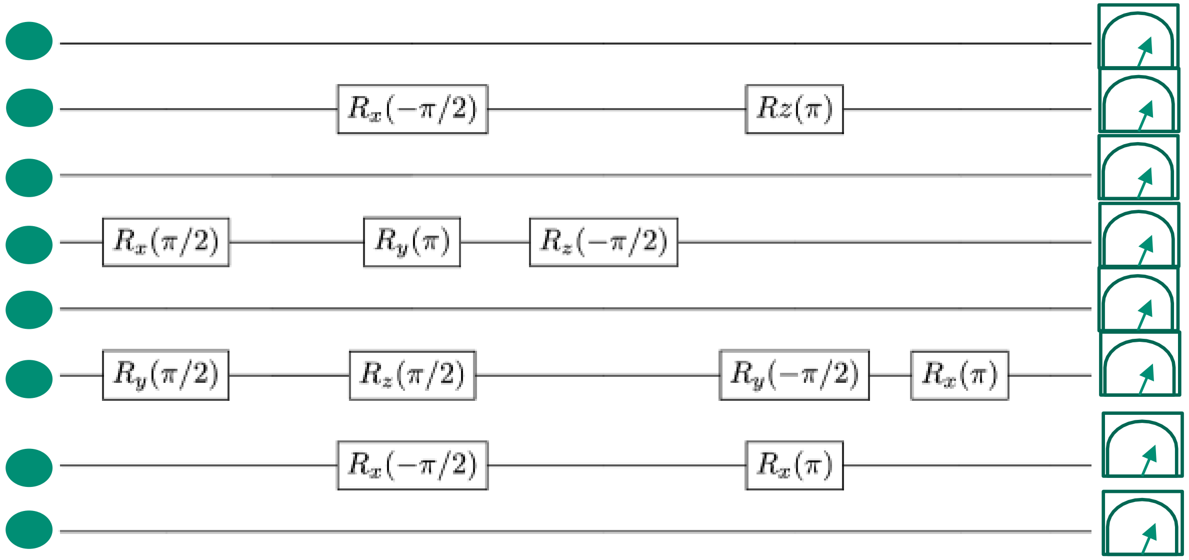
QSCOUT

Multiple ion techniques

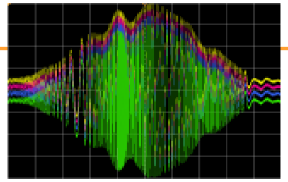
Individually address ions or pairs of ions

A quantum assembly language to specify gates

JAQAL



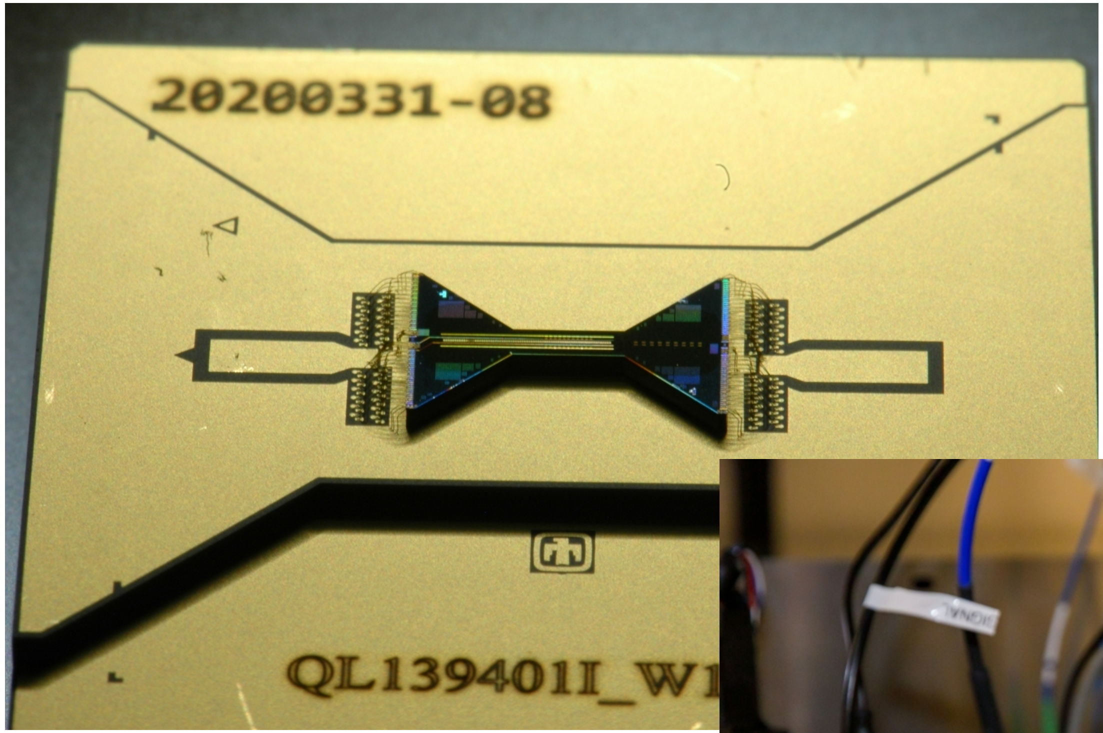
New hardware for advanced pulse/gate generation

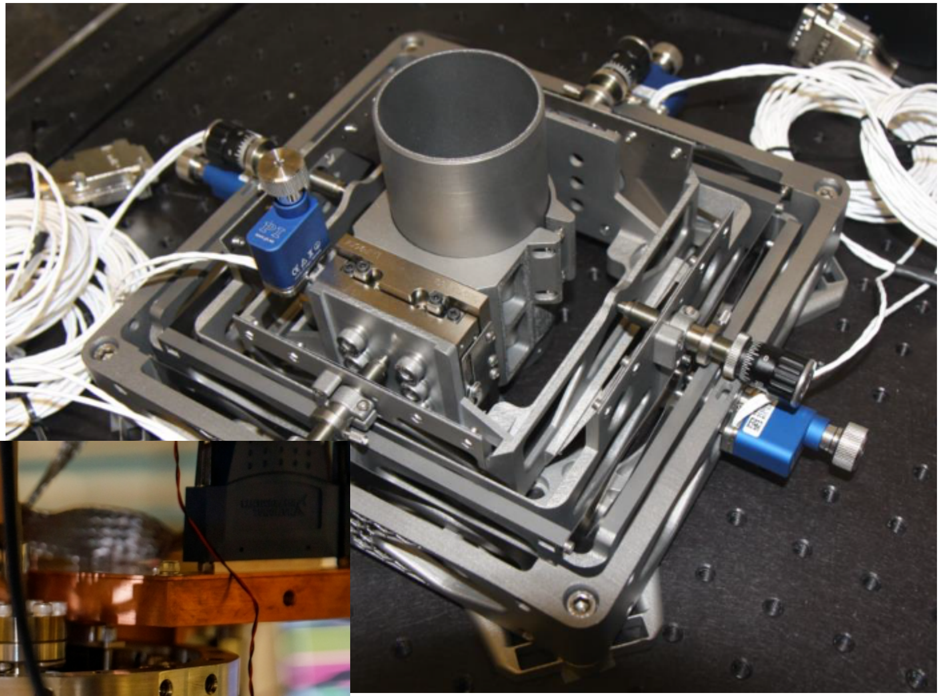


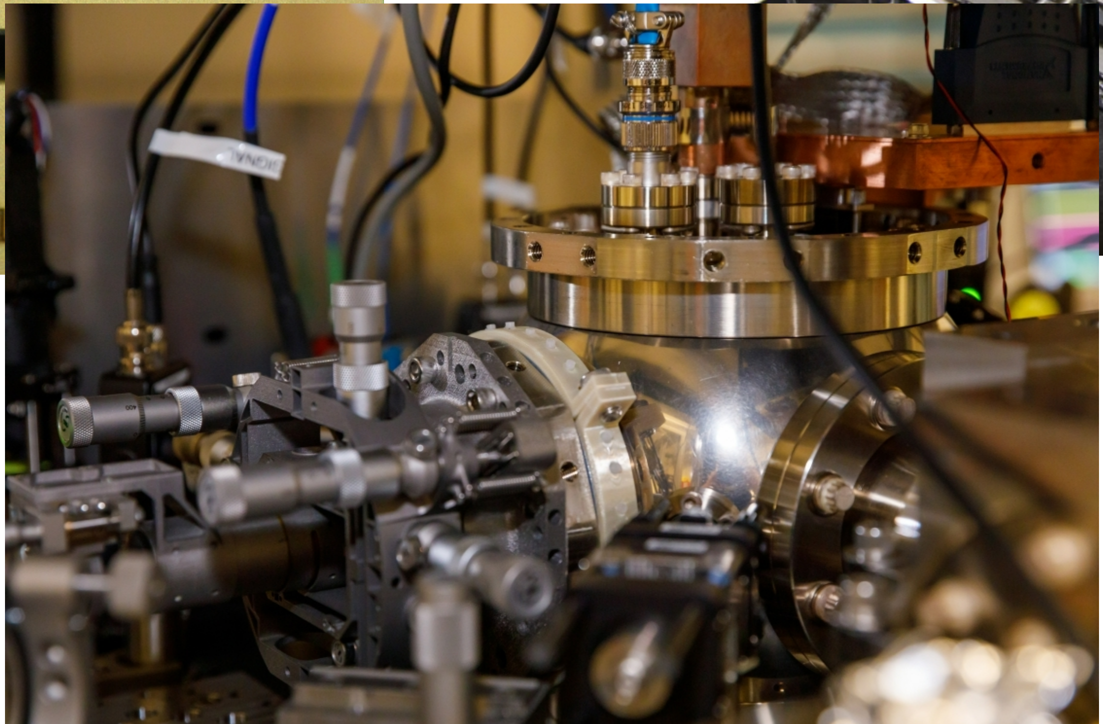
Distinguishable detection of each ion (*which* ion is in 1 or 0)

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

Complete quantum systems require mechanical engineers, optical engineers, software engineers, physicists, fabrication specialists,.....



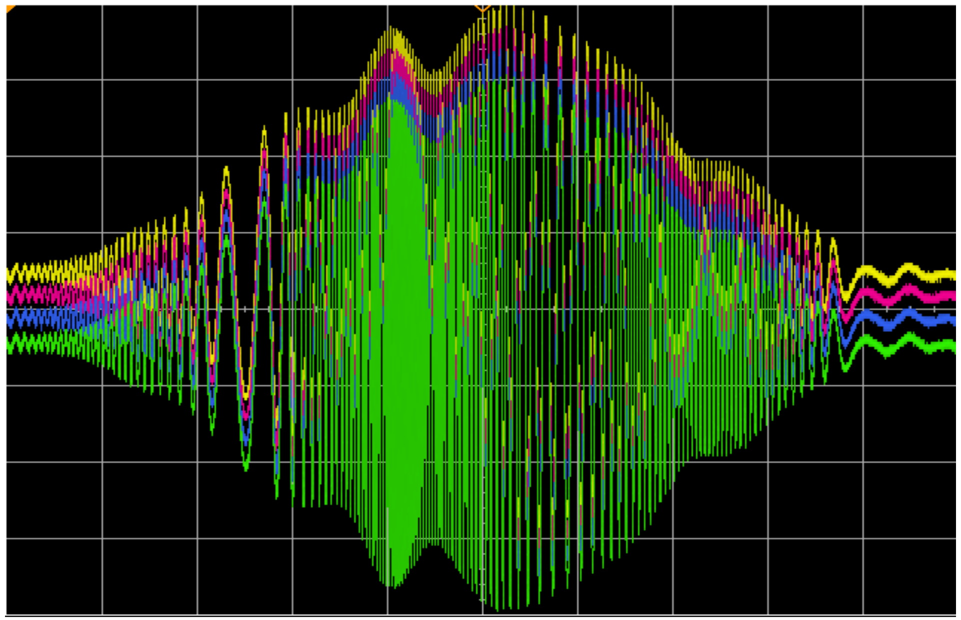




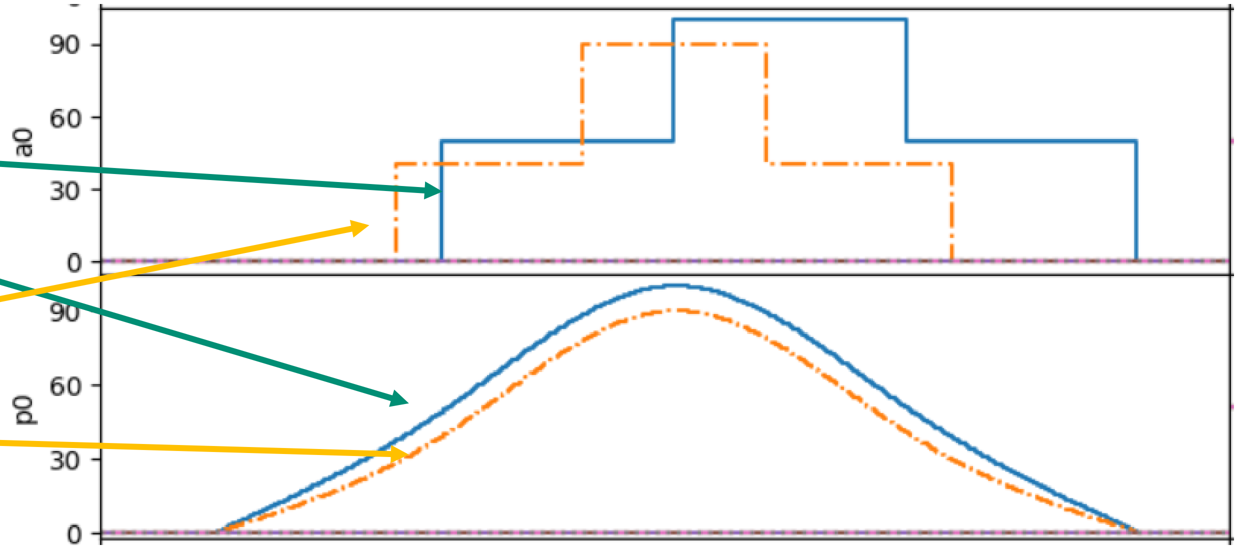
New hardware for advanced coherent pulse generation: RFSoC

- Two tones per channel
- Coherent output synchronized between all channels
- Pulse envelopes and frequency- phase- modulation defined by splines
- Compact representation of gates for efficient streaming of circuits
- AOM Cross-talk compensation
- Z-gates performed in software
- Multi-tile sync for multiple boards

Dan Lobser



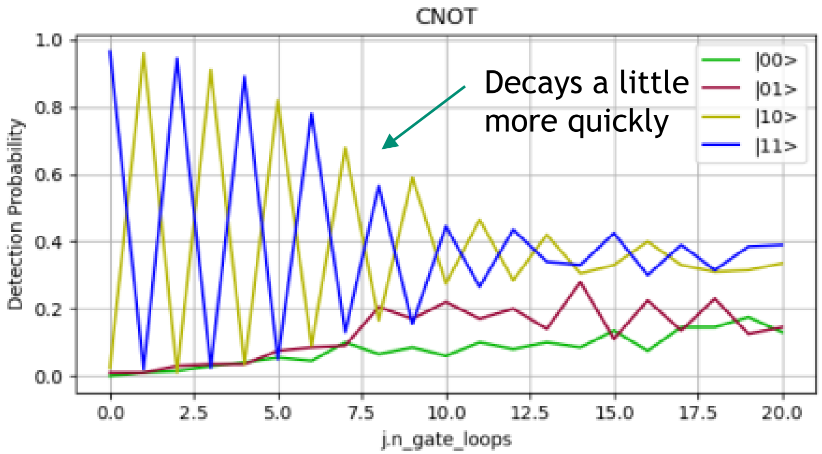
```
def gate_counterprop_x(self, channel, duration_scale=1):
    return [PulseData(0, duration_scale*self.pulse_duration,
                      freq0=self.freq0,
                      freq1=self.freq1,
                      amp0=[0,50,100,50],
                      phase0=(0, 50, 100, 50, 0),
                      enable_mask=1, sync_mask=3),
            PulseData(channel, duration_scale *
self.pulse_duration,
                      freq0=self.freq0,
                      freq1=self.freq1,
                      amp0=[0,40,90,40,0],
                      phase0=(0,40,90,40,0),
                      enable_mask=2, sync_mask=3)
            ]
```



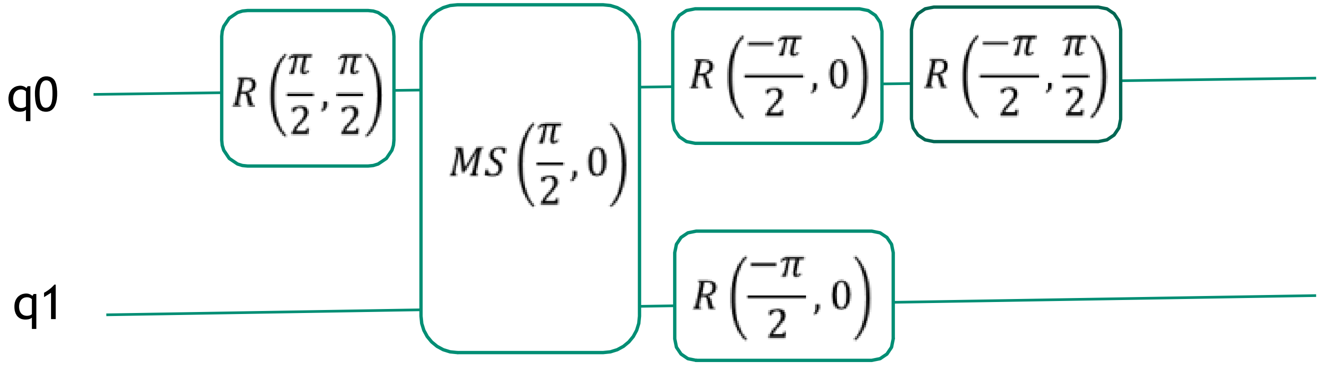
Experimental subtleties: Specialized gates exposed problems

CNOT inverse gates perform better than **CNOT** gates: still a mystery: mismatch in positive and negative rotation angles

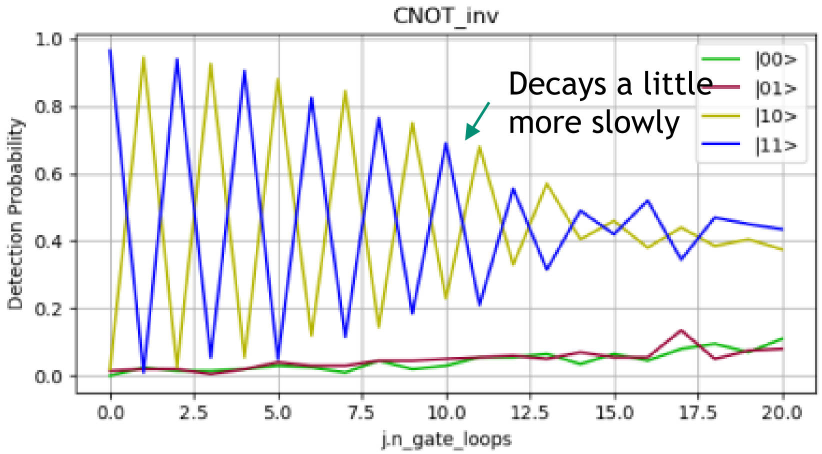
Repeated CNOT gates, starting in |11>



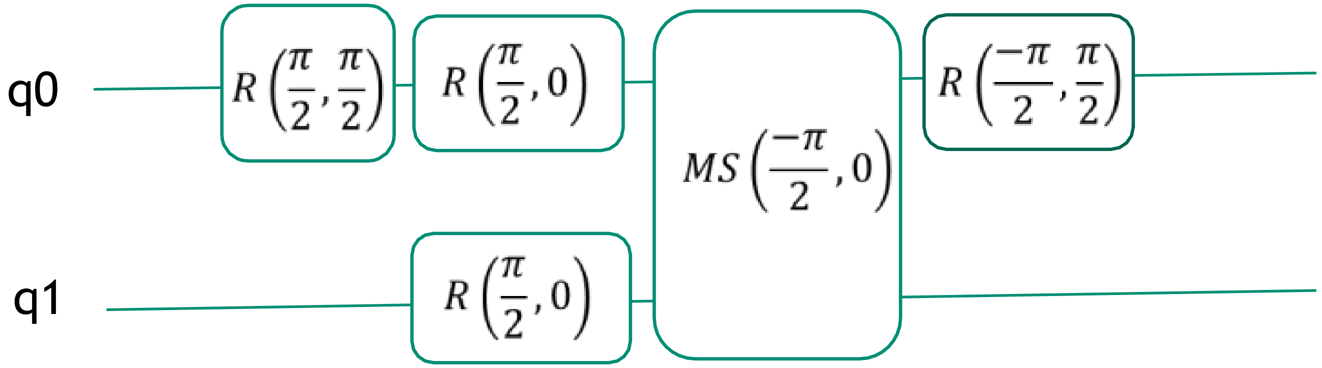
CNOT circuit:



Repeated CNOT inverse gates, starting in |11>



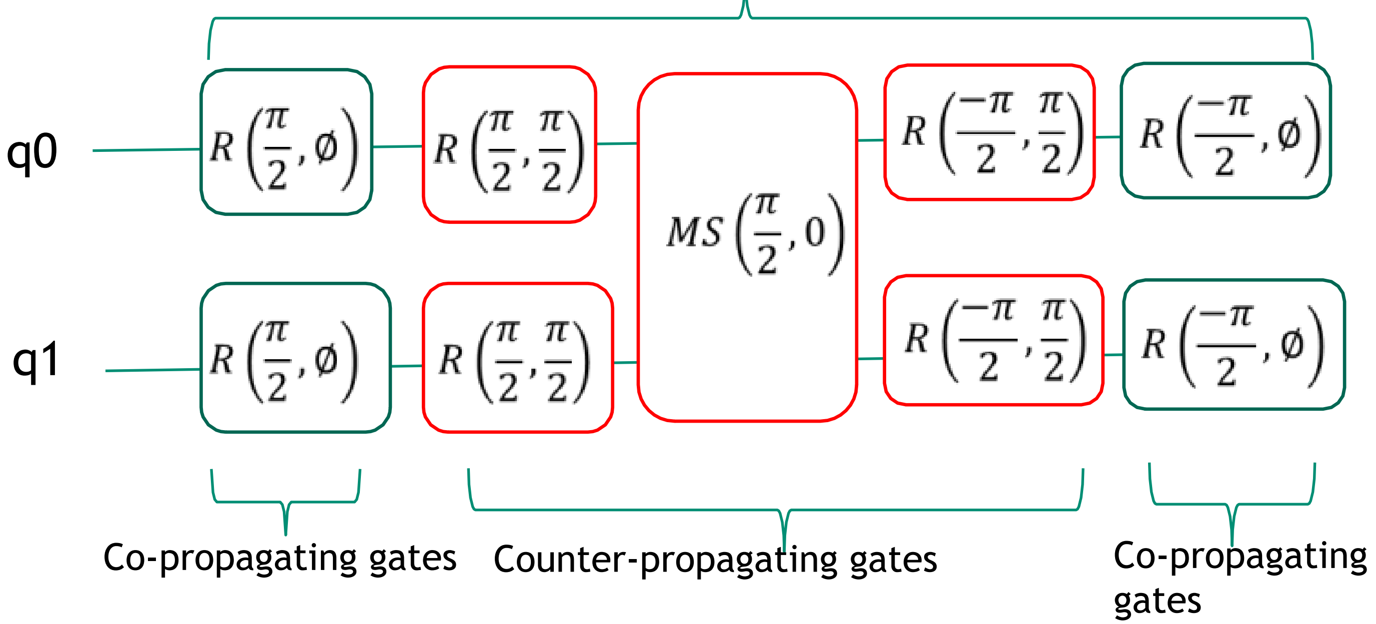
CNOT inverse circuit:



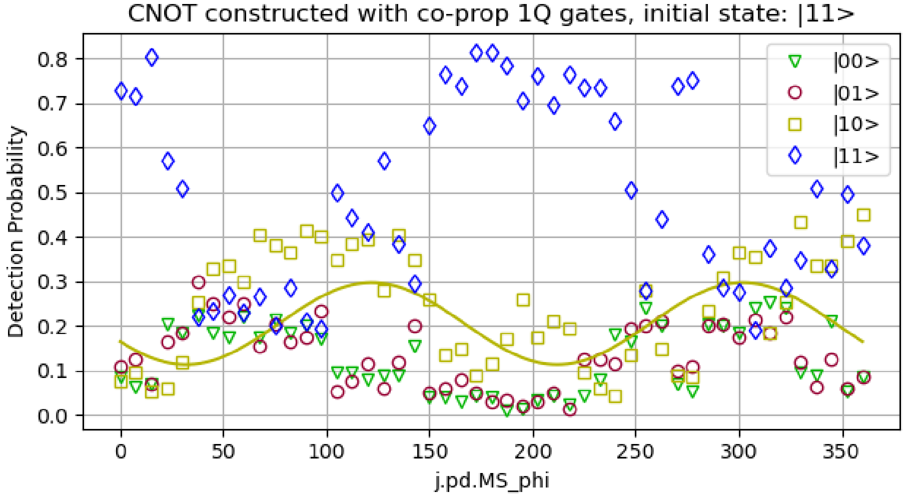
Experimental subtleties: Other phase errors

Making high-fidelity single-qubit gates compatible with 2-qubit gates:

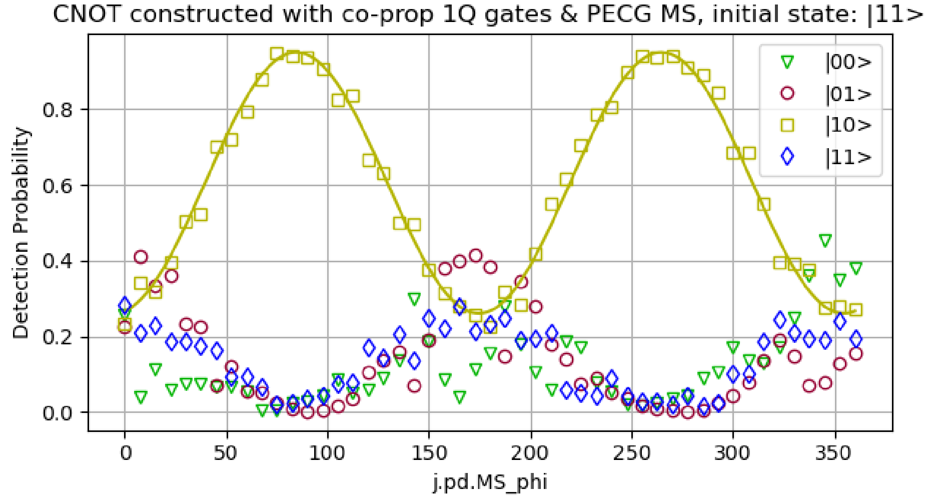
$MS\left(\frac{\pi}{2}, \emptyset\right)$:



Without extra counter-propagating gates:



With extra counter-propagating gates:



First round user interactions: emphasis on benchmarking

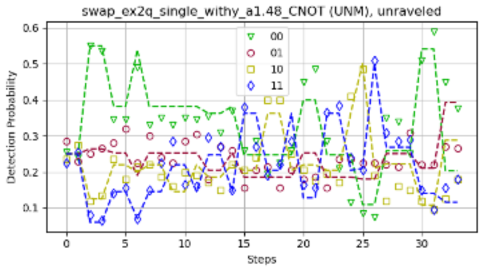
QSCOUT

- Call for proposals March 2020, 15 received, 5 selected
- First user generated Jaqal code performed Feb. 2021
- First round, 3-ion processor emphasis on benchmarking
- **Second call for proposals ended June 18 2021**

THE UNIVERSITY OF NEW MEXICO

Digital simulation of non-stoquastic Hamiltonians

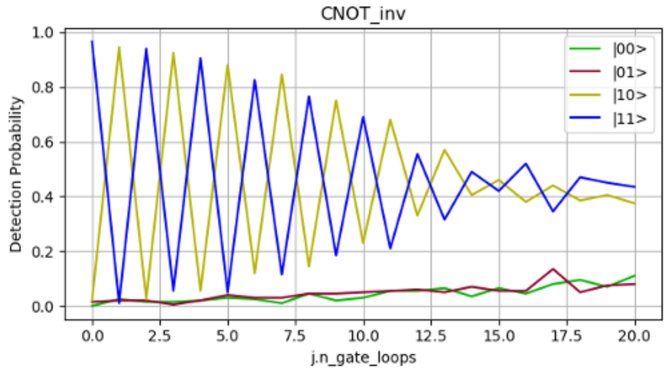
Tameem Albash
Elizabeth Crosson
Milad Marvian

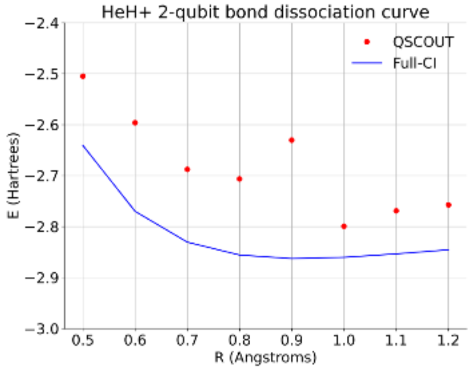


OAK RIDGE National Laboratory

Connecting low level characterization metrics to higher level algorithmic performance with a tractably small simulation

Raphael Poozer





IBM

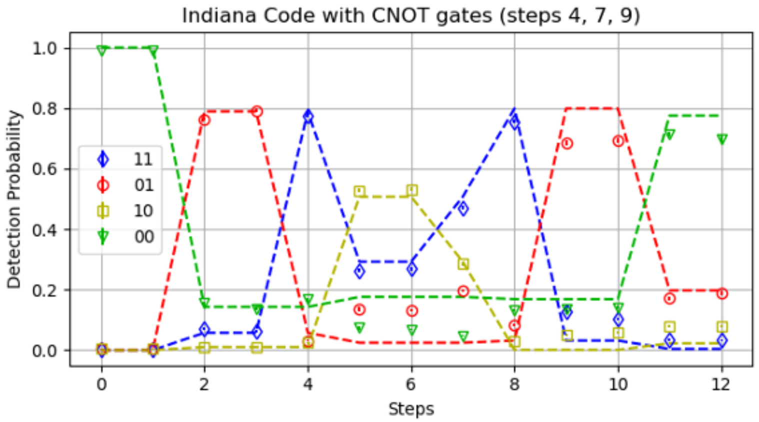
Petar Jurcevic

Benchmarking through Quantum Volume

INDIANA UNIVERSITY BLOOMINGTON

Simulate the quantum dynamics of proton-coupled electron transport problems in quantum chemistry

Philip Richerme



Berkeley UNIVERSITY OF CALIFORNIA

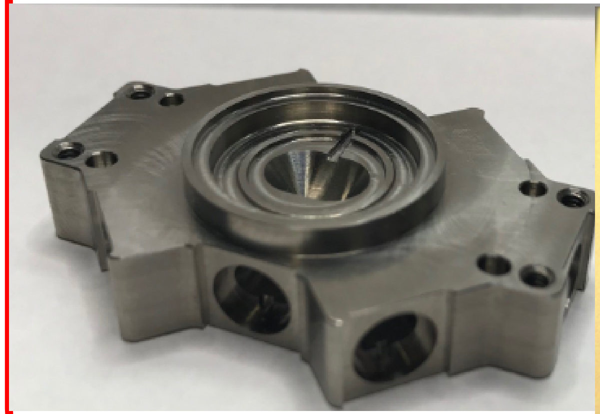
Ryan Shaffer
Hang Ren
Hartmut Haffner

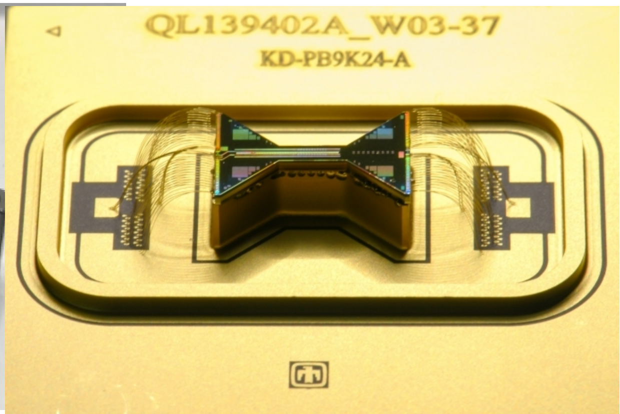
Assessing the Performance of the Analog Randomized Benchmarking protocol for gate-based devices

Future upgrades: more ions, partial measurements

QSCOUT 1.0 (current)	QSCOUT 1.1 (10 ion goal) 9/2021	QSCOUT 2.0 (cryo) 7/2022	QSCOUT 1.2 (Partial meas.) 11/2022	Beyond QSCOUT >9/2023
3 ions	5-11 ions	>10 ions	>10 ions Partial measurements	QSA 32 ion machine

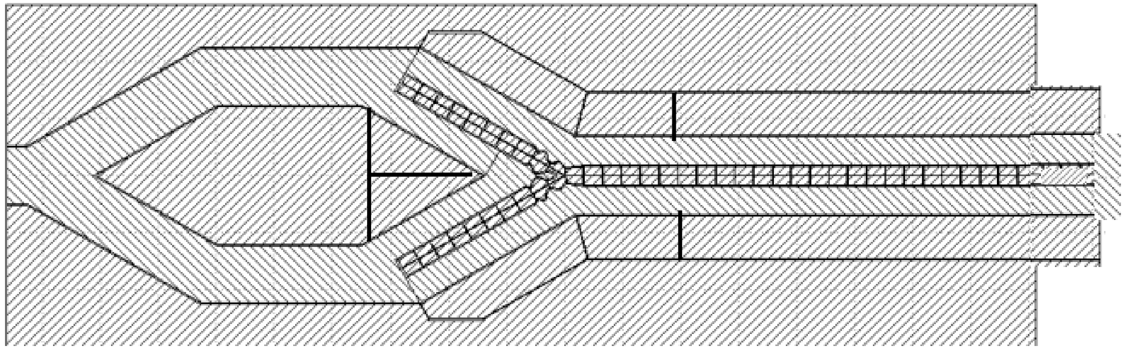
Cryo, *under development (better ion lifetime, less ion heating = higher fidelity gates)*





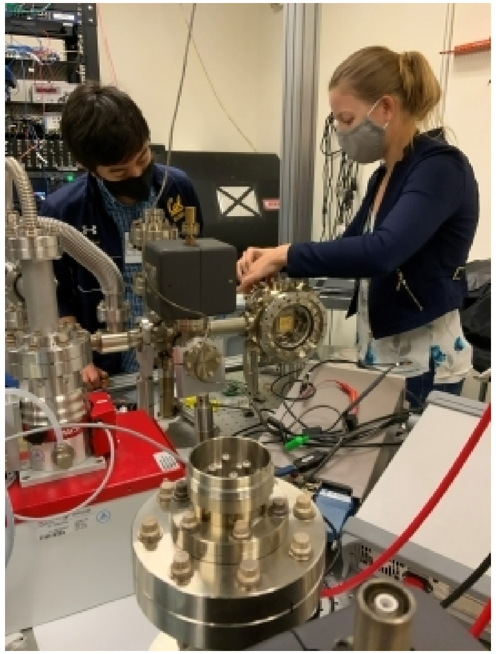
Cold Quanta

New trap design for re-ordering ions, enables partial measurements



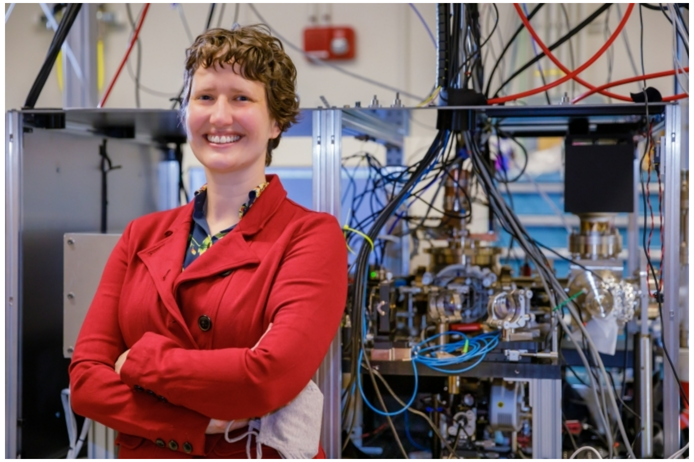
Getting involved, more information

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



Melissa Revelle and Matt Chow

Ray Haltli and Josh Wilson



Susan Clark
Ashlyn Burch
Matt Chow
Craig Hogle
Megan Ivory
Dan Lobser
Peter Maunz
Melissa Revelle
Dan Stick
Andrew Van Horn
Josh Wilson
Chris Yale

Brad Salzbrenner
Madelyn Kosednar
Jessica Pehr
Ted Winrow
Bill Sweatt
Dave Bossert

Andrew Landahl
Ben Morrison
Tim Proctor
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Antonio Russo
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Matt Delaney