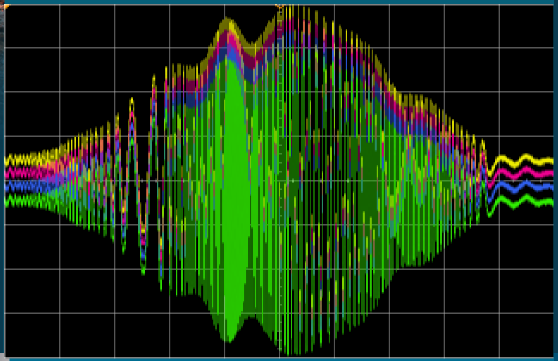
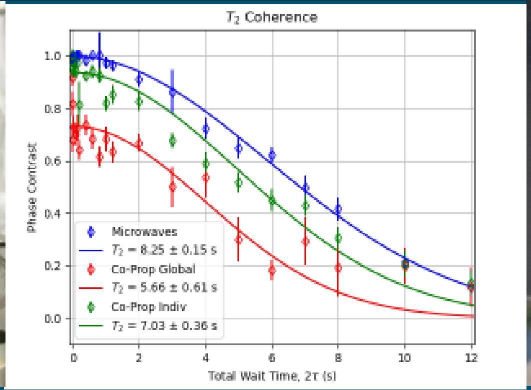
SAND2021-12215PE

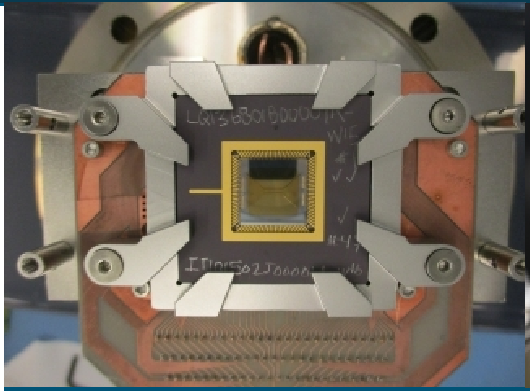
Sandia National Laboratories

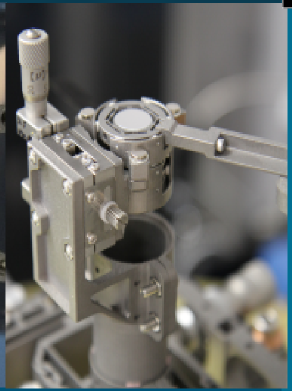
QSCOUT



QSCOUT







U.S. DEPARTMENT OF ENERGY
Office of Science

PRESENTED BY

Ashlyn Burch, Susan Clark, Dan Lobser, Melissa Revelle, Chris Yale

U.S. DEPARTMENT OF ENERGY NNSA

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Agenda

- User agreement updates
- Sending and receiving files
- How the hardware works
- Current capabilities
- Current status/scheduling
- Special topics of interest

- Example input/output file

User agreements update

QSCOUT

https://www.sandia.gov/quantum/Projects/QSCOUT_Call2021.html

Proposal Deadline Complete

Proposals due **June 18, 2021**, at 11 pm MDT (UTC-6).

Experiments expected to start **August 2021**. There is no guarantee that the system is available at this time.

Download this call in pdf format here.

The Quantum Scientific Computing Open User Testbed (QSCOUT) is a 5 year DOE program to build a quantum testbed based on trapped ions that is available to the research community. As an open platform, it will not only provide full specifications and control for the realization of all gate-level quantum and classical processes, it will also enable researchers to investigate, alter, and optimize the pulse level gate implementations of the testbed and evaluate more advanced gate implementations of quantum operations.

QSCOUT will be made operational in stages, with each stage adding more ion qubits, greater classical control, and improved fidelities. We are excited to collaborate with the broad quantum computing community.

Who can be a QSCOUT User – Individuals and teams from industry, academia, and government institutions from around the world are invited to submit proposals to use the QSCOUT testbed. As a DOE funded testbed, QSCOUT provides access to its staff and quantum computing resources at no fee to approved users for non-proprietary quantum information processing research.

What will be available – The QSCOUT testbed is based on hyperfine clock-state qubits stored in trapped ytterbium-171 ions. A quantum register is realized by a chain of ions

Quick Links

Templates:

- Word Template
- Latex Template

Example User Agreements:

- Private Company
- University
- National Lab

Machine Interface:

- Jaqal Language
- JaqalPaq
- JaqalPaw (Pulses and Waveforms)

Proposals due 6/18/2021, at 11 pm MDT (UTC-6).

Questions? email qscout@sandia.gov

Main Points:

- You have sole use of the data for 9 months, then it is allowed to be made public (by outside request – unlikely)
- Publications must include funding statement: *"This material was funded [in part] by the U.S. Department of Energy, Office of Science, Office of Advanced Scientific Computing Research Quantum Testbed Program."*
- Joint publications with Sandia researchers are required to go through Sandia internal review (you do not have to publish jointly if you do not wish to)
- Agreements are good for 5 years (if you successfully reapply, you won't have to sign another user agreement)
- Do not send us anything proprietary!

Sending Jaqal files and Receiving Data

QSCOUT

- Work with your POC over email
- If you would like to set up a slack or gitlab page through your institution, we are happy to work with you

Jupyter notebooks vs. pure Jaqal files?

- Often we will split up pure jaqal files for troubleshooting using Jupyter notebooks
- If you can send it as a notebook that works with the emulator, it is easy for use to run it on the experiment.
- Some options for JaqalPaw pulse checker

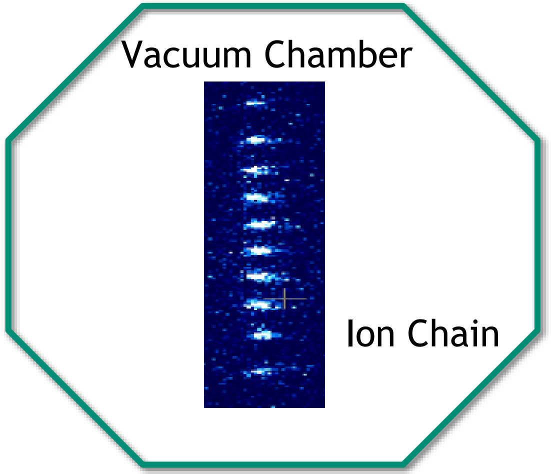
```
In [6]: e00 = np.empty(len(Angles))
e01 = np.empty(len(Angles))
e10 = np.empty(len(Angles))
e11 = np.empty(len(Angles))
for angles in range(0,len(Angles)):
    code = "\n".join(["from qscout.v1.std usepulses *"]+jc_header[angles]+[gates])
    emulator_code = code
    res = emulator.run_jaqal_string(emulator_code)
    print(f"{str(angles)} // {res.subcircuits[0].probability_by_int}")
    e00[angles] = res.subcircuits[0].probability_by_int[0]
    e10[angles] = res.subcircuits[0].probability_by_int[1]
    e01[angles] = res.subcircuits[0].probability_by_int[2]
    e11[angles] = res.subcircuits[0].probability_by_int[3]

timestamp_emu = timestamp_generate()

#print(e00)
```

```
0 // [0.00124896 0.00124897 0.49875103 0.49875104]
1 // [0.02561861 0.07008794 0.25390767 0.65038577]
2 // [0.03025058 0.24908595 0.03535759 0.68530588]
3 // [0.09188404 0.39710296 0.07364314 0.43736986]
4 // [0.33794116 0.22487669 0.32681455 0.1103676 ]
5 // [0.04366608 0.04366617 0.45633383 0.45633392]
6 // [0.03705222 0.11076637 0.28569314 0.56648827]
7 // [0.01292919 0.2869392  0.20963114 0.49050047]
8 // [0.04381479 0.5262658  0.27828702 0.15163238]
9 // [0.44094748 0.16446409 0.29458973 0.0999987 ]
```

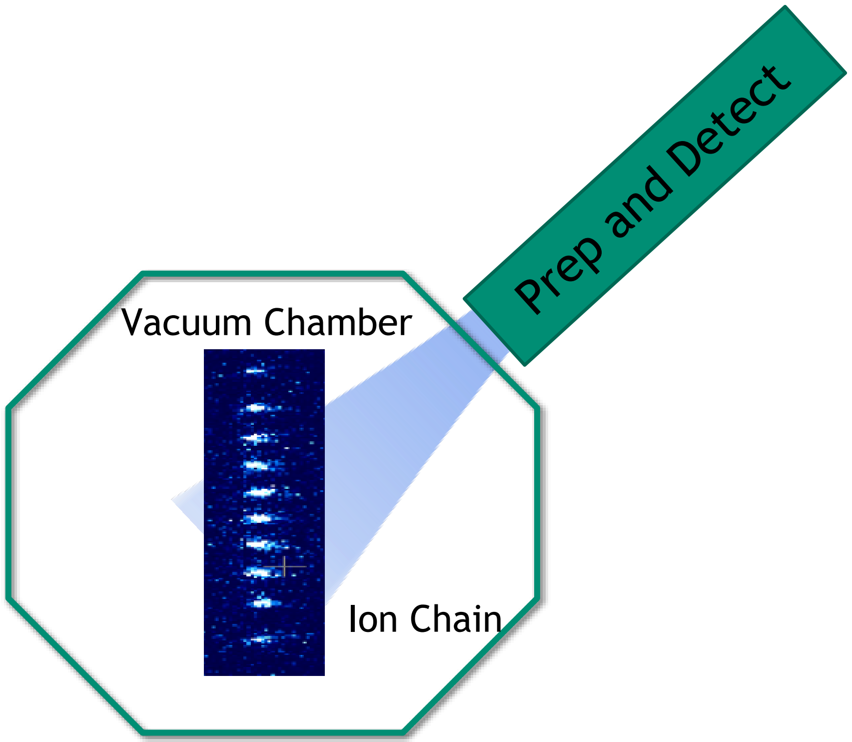
Section from QSCOUT example notebook calling the emulator

QSCOUT hardware: trapped ions

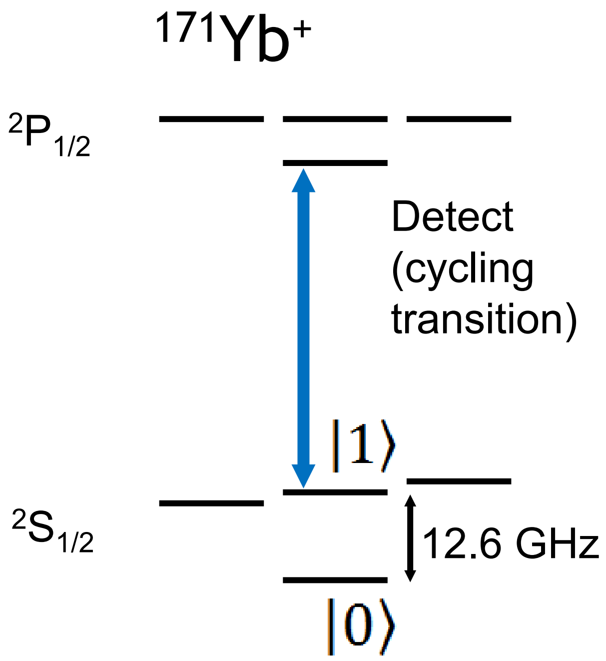
Trapped ions, fully-connected, individually-addressed, distinguishably detectable system

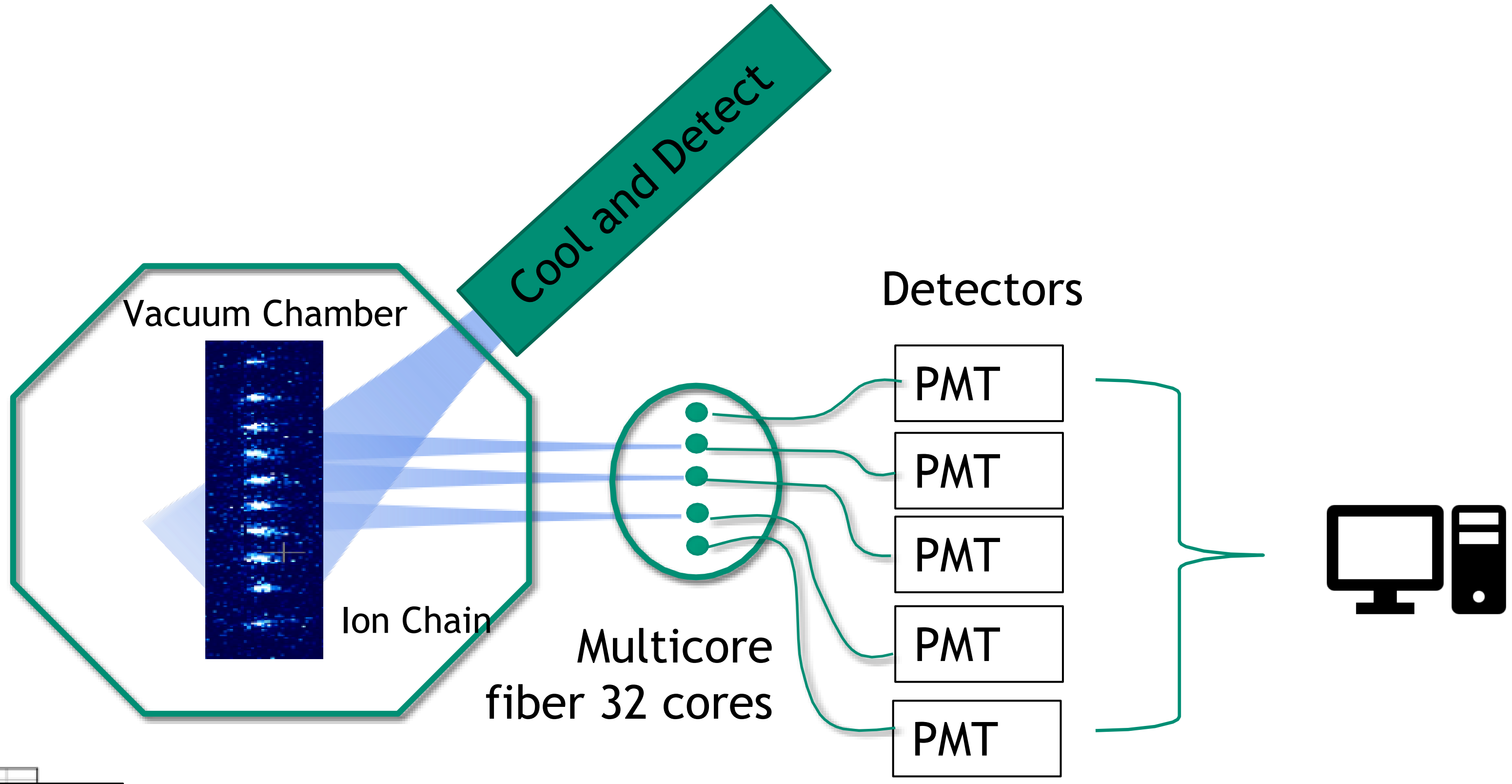


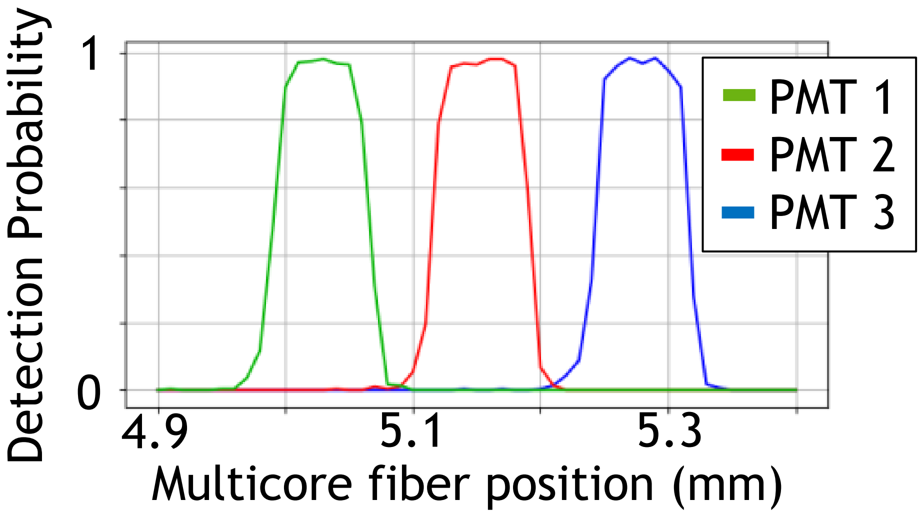
Flood beam for preparation and measurement, currently no independent prep or measure on QSCOUT



Distinguishable detection (light from each ion goes to its own detector)







During detection, light from each ion is collected separately

Depending on # of photons collected, ion is determined to be bright (1) or dark (0)

Two or three frequencies required for qubit spin manipulation copropagating or counterpropagating configurations as needed

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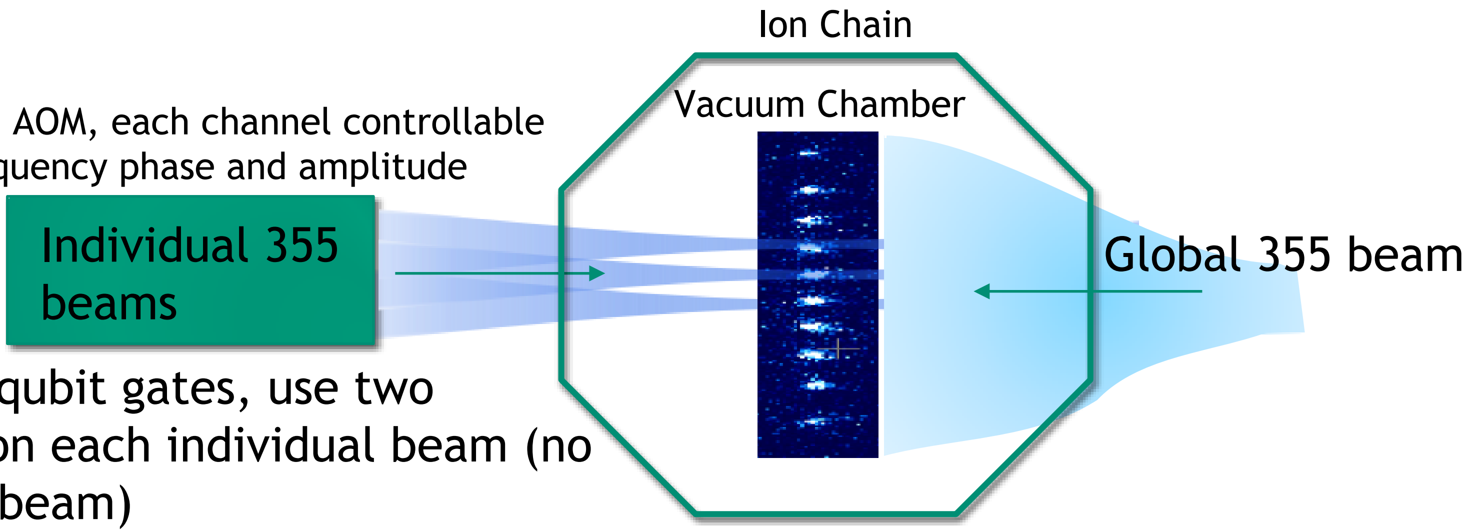
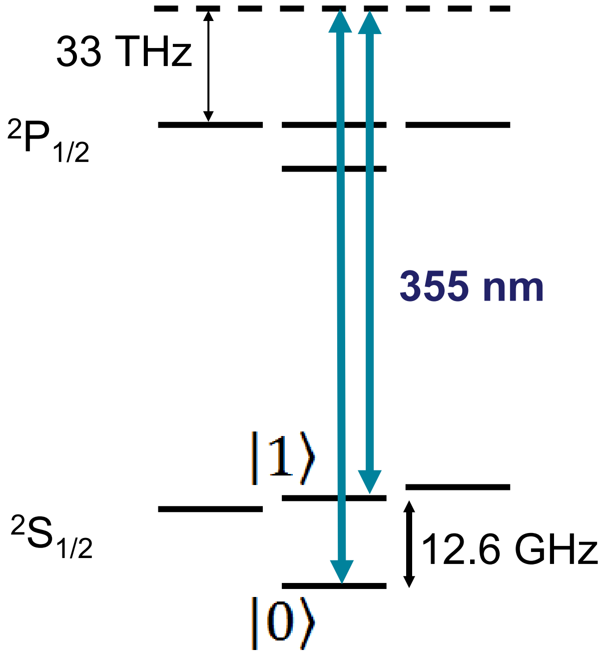
32 channel AOM, each channel controllable in frequency phase and amplitude



Single qubit gates, use two tones on each individual beam (no global beam)

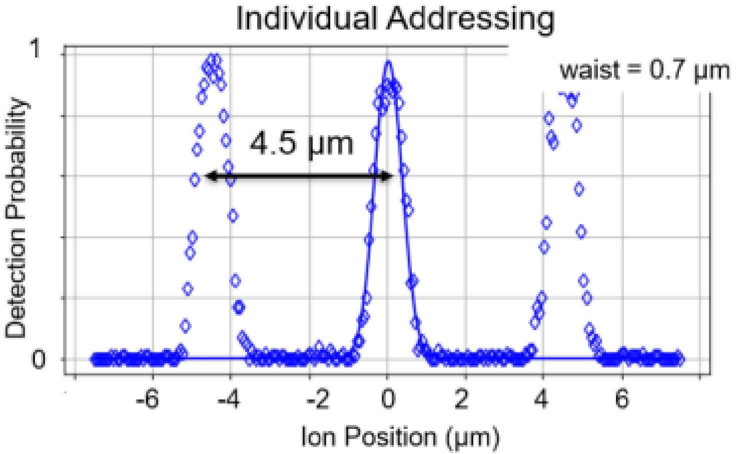
Each spin flip needs two tones



Two Qubit Gates with Trapped Ions:

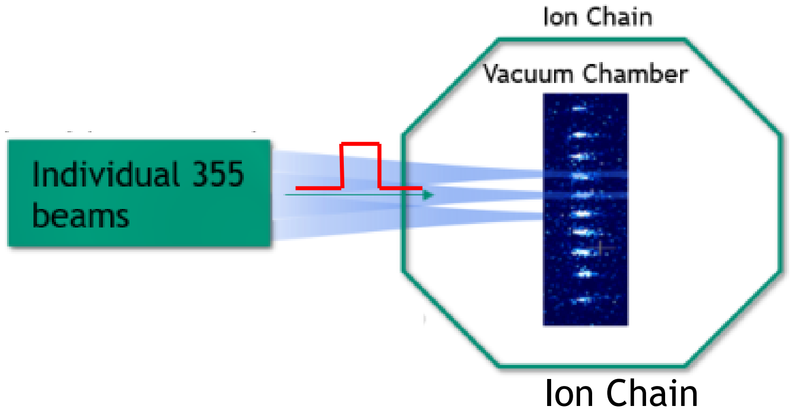
- Mølmer-Sørensen[1] σ_x x σ_x entangling interaction
- Three frequencies required, counterpropagating configuration required (2 freq on individual channel, 1 freq on global channel)
- Any pair of ions can be illuminated, excite and de-excite motion of whole chain, only illuminated ions experience spin flip needed for entanglement

[1]Mølmer and Sørensen, *PRL* **82,** 1835 (1999)



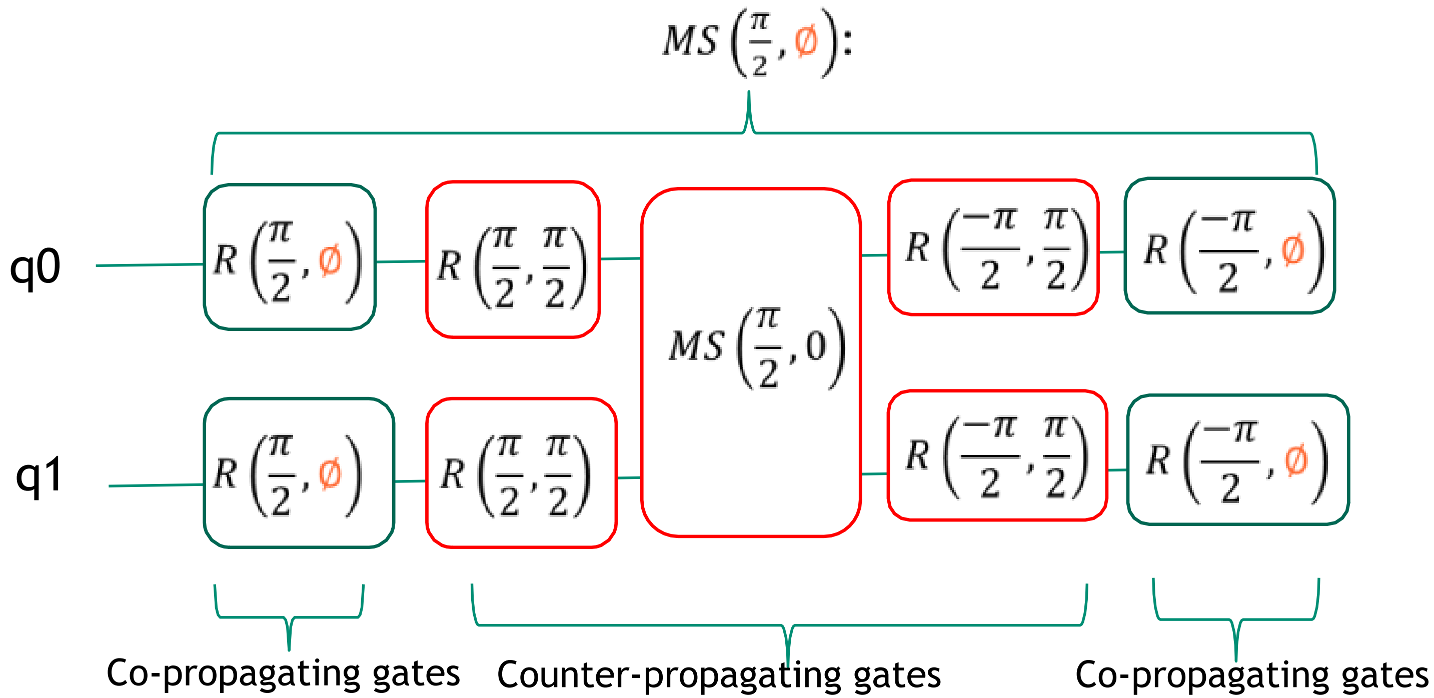
Current default gates:

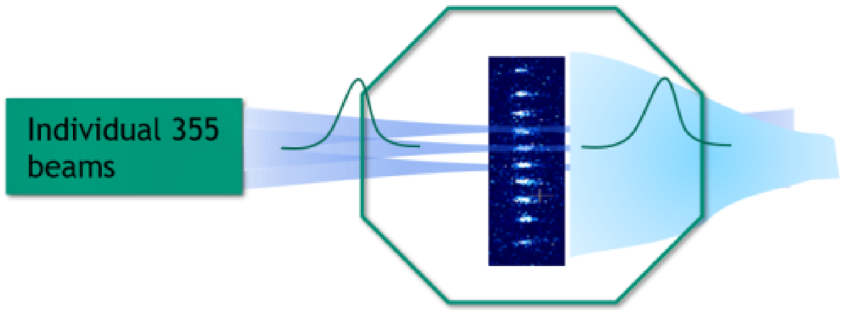
- **Idle gate**: do nothing
- **Single qubit**: Copropagating tones, ~25 us square pulse amplitude



No global beam

- **Two-qubit**: Phase error corrected MS gates with sqrt(Gaussian) envelope on **global and individual** beams:





Calibration routine for 2-qubit gate

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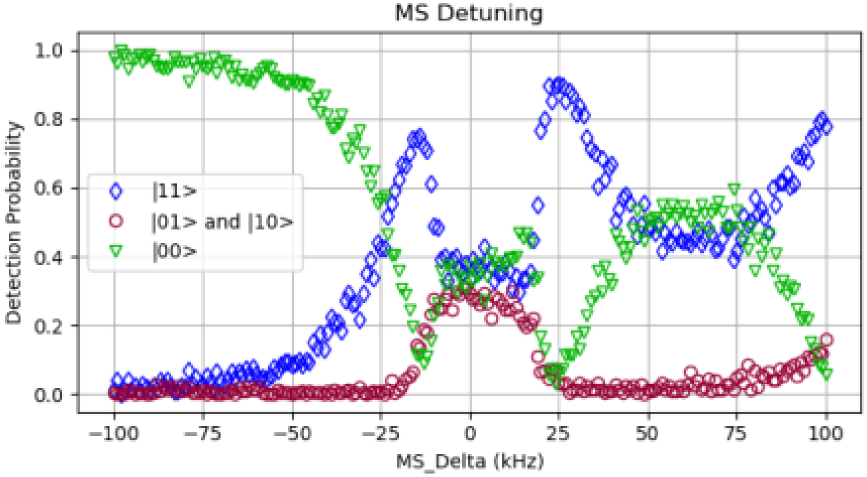
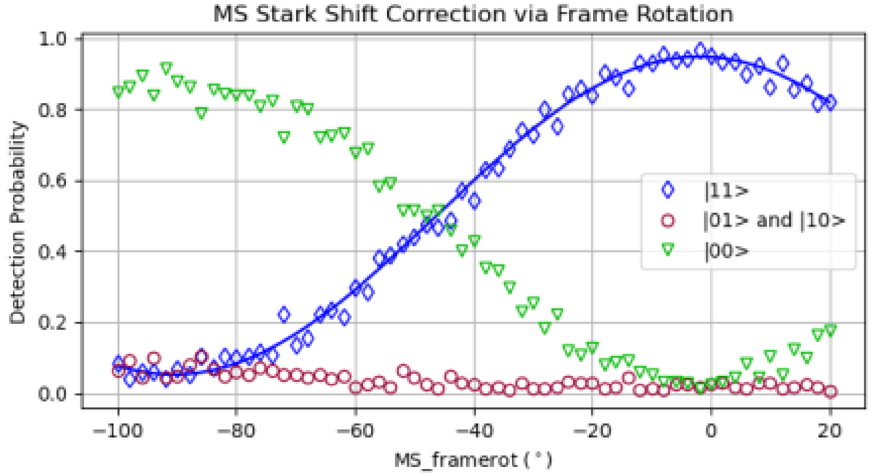
How do we calibrate our two qubit gates to play nice with the other gates?

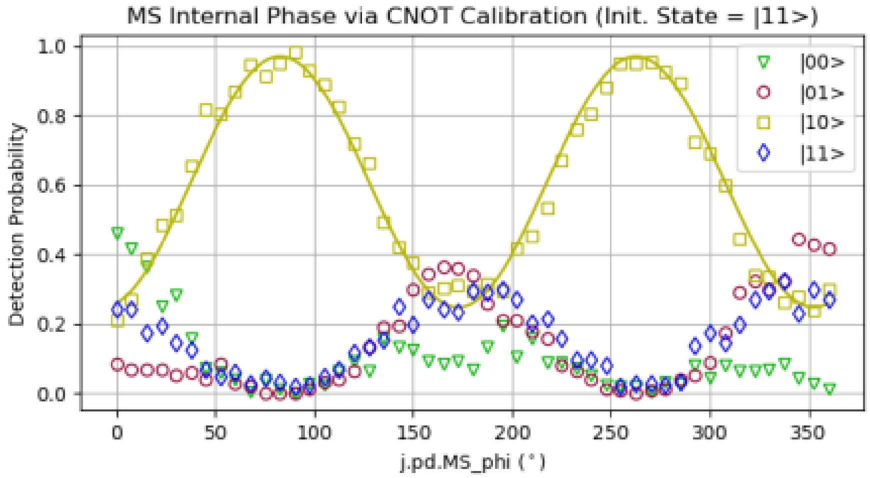
1. Detuning for |00>/|11> crossing



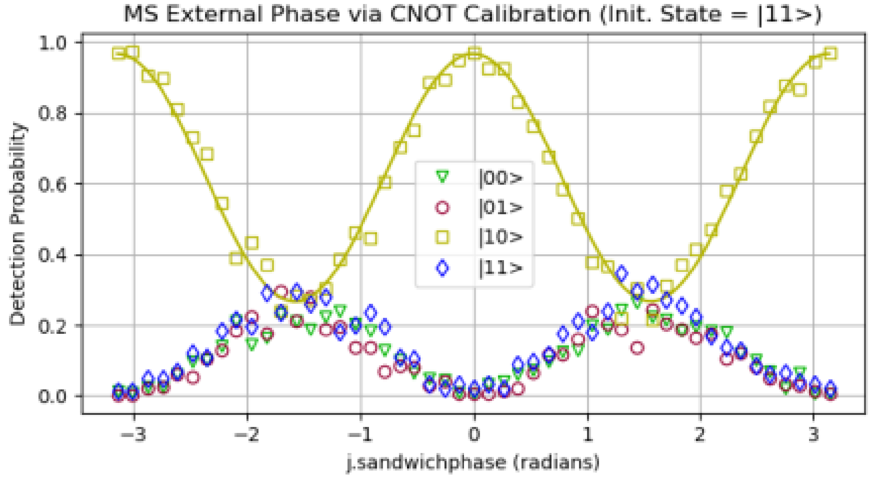
2. Frame rotation to account for AC Stark shift



3. Phase relation of MS Raman beams via CNOT



4. External phase relation via CNOT for sandwiched MS



Two exemplars describing this process in relation to Jaqal and JaqalPaw will be available soon!

Current capabilities

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- 2 ions
- 95-98 % fidelity 2-qubit gate
- ~ max 15: 2-qubit gates/circuit
- ~ max 800 1-qubit gates/circuit
- We can provide other requested calibration parameters if you are interested

Promised Capabilities with schedule : (will be adding as needed)

- 1,2, and 3 ion codes will be run first
- 5-11 ions (trap swap etc.), will be run later
- 98 % fidelity 2-qubit gate between any pair

Extra Slides

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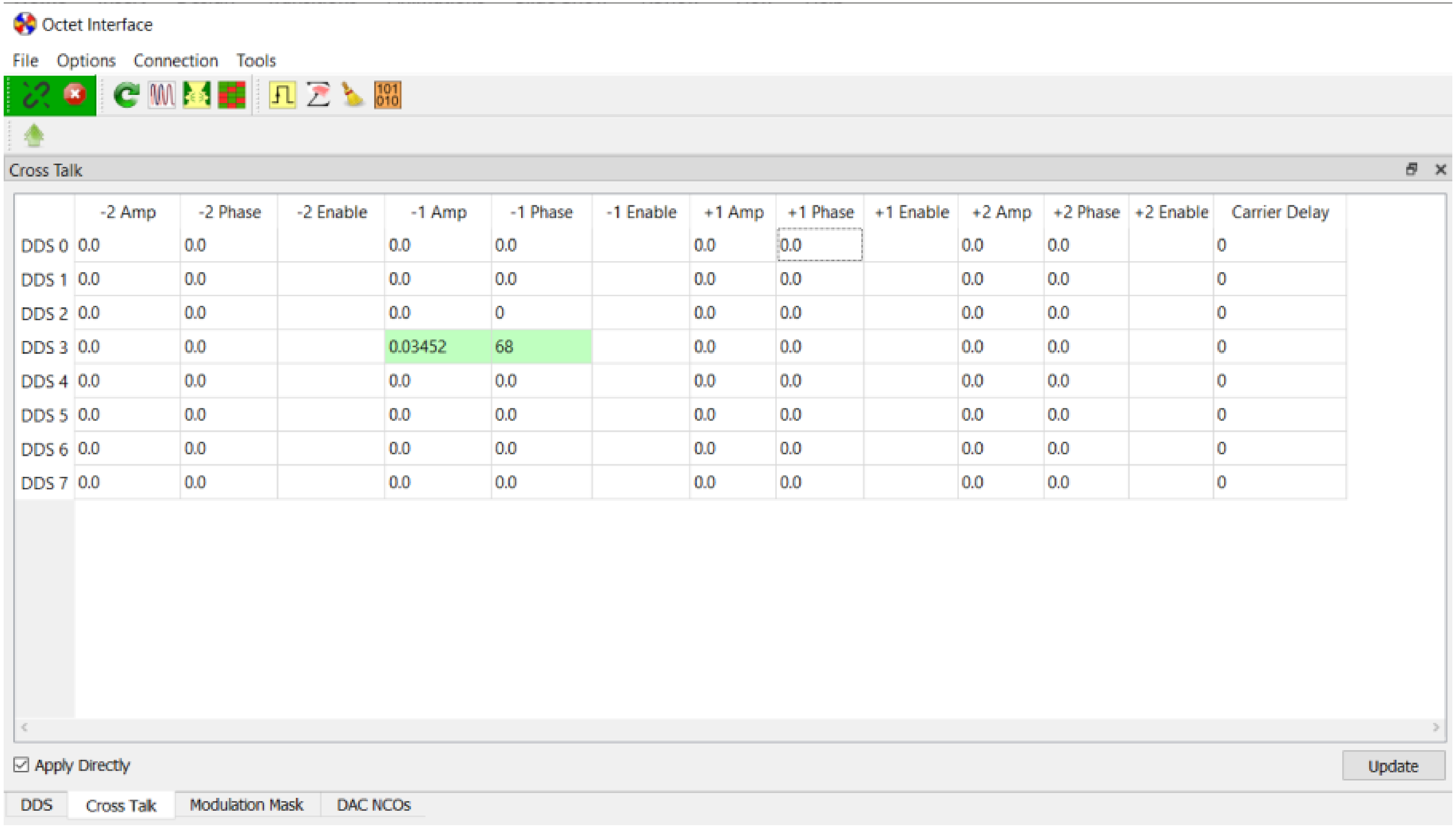
Behind the scenes crosstalk:



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Behind the scenes crosstalk demonstrated when attempting crosstalk compensation

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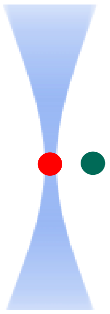
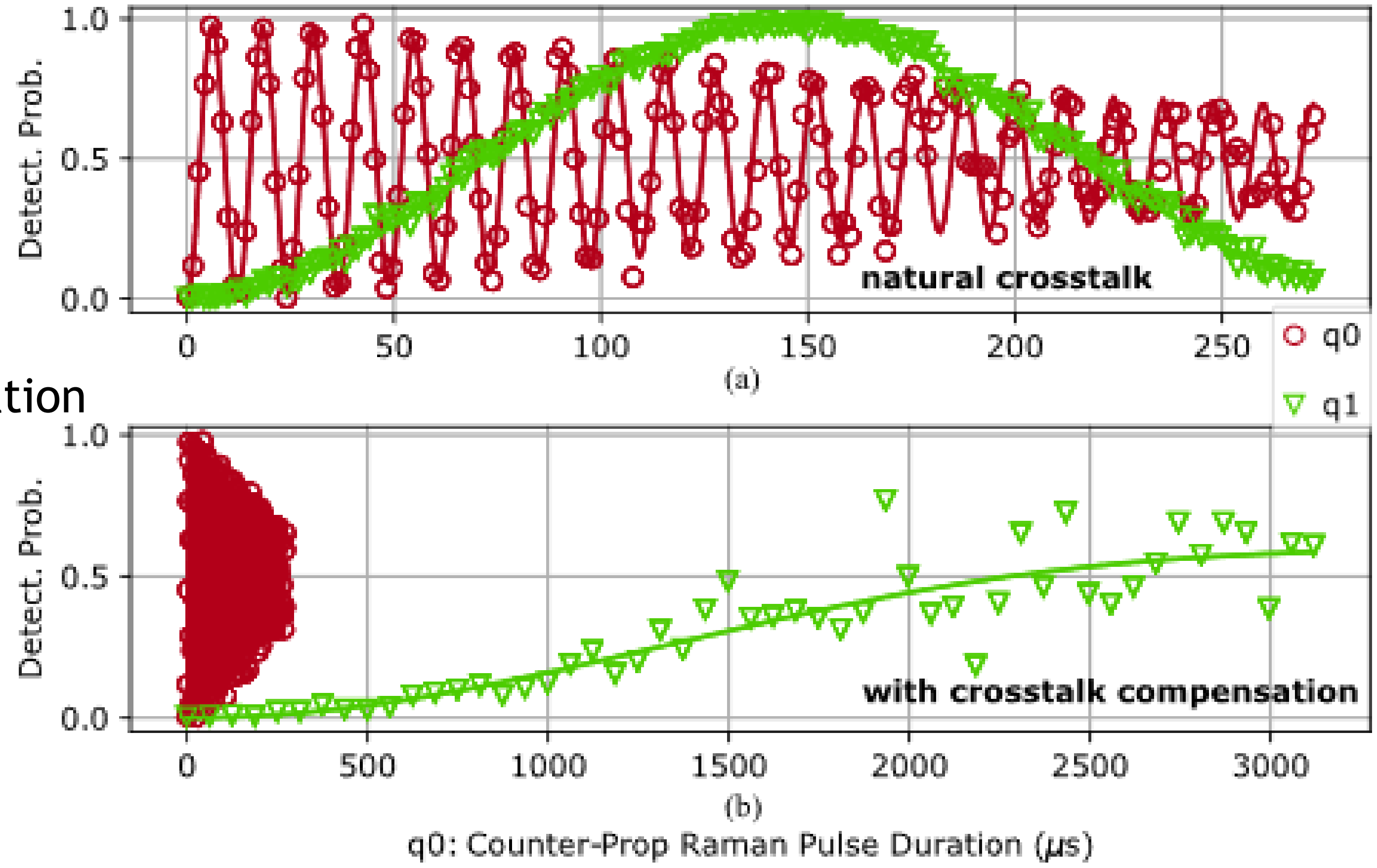
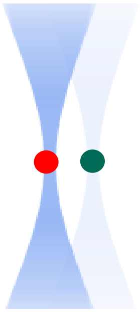




Crosstalk compensation



Rabi period ratios:

4.1 %

0.17 %