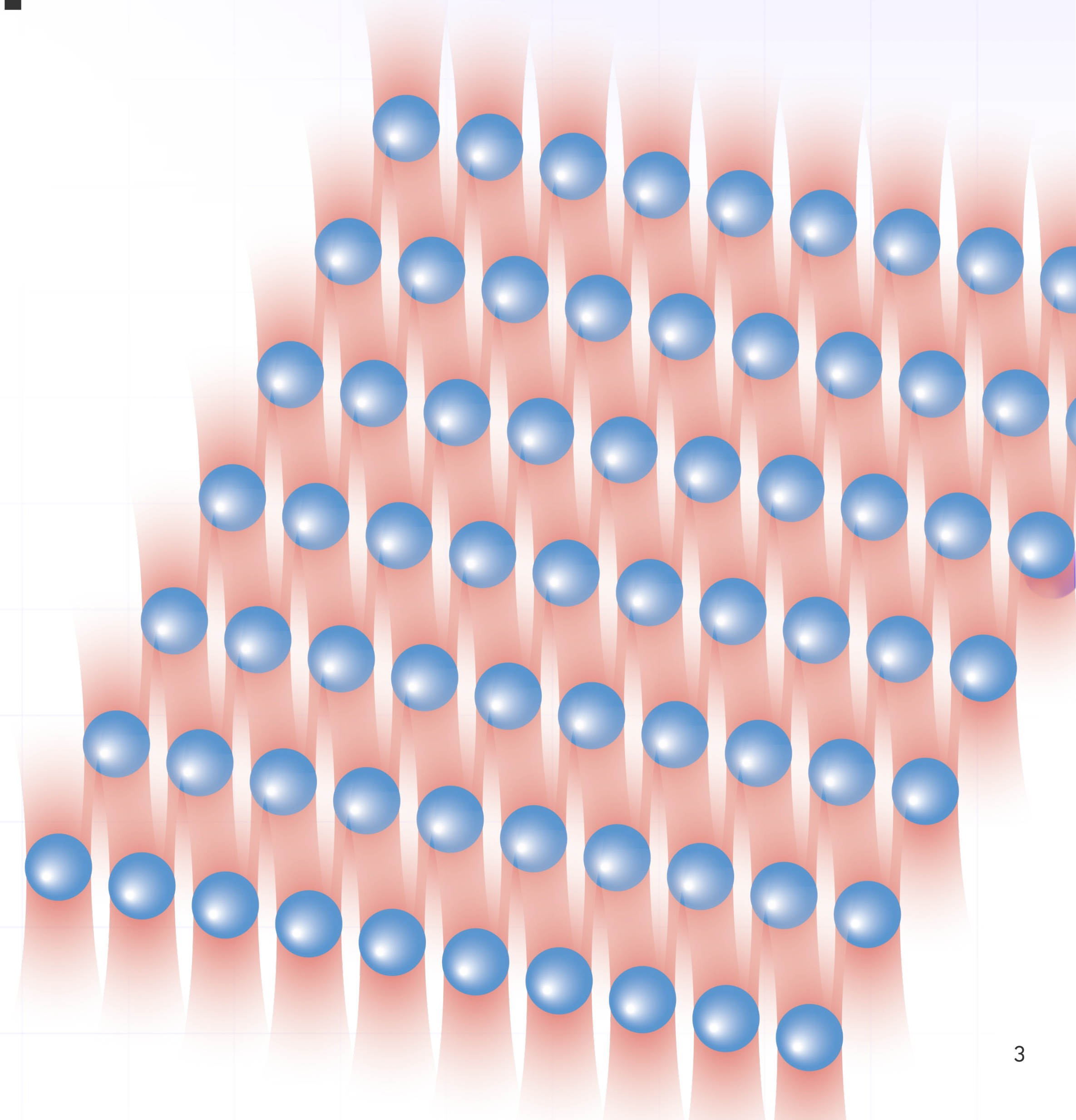
Session I: Basics

House rules (if you want to get the most of this activity)

- Videos on
- Mics muted (unless want to speak)
- Interrupt facilitator as much as possible! (raise hands or unmute and speak at will)

Neutral-atom quantum processor

- Densely packed qubits (atoms)
- Efficient qubit control
- Flexible problem encoding
- New ways to think quantum computing!



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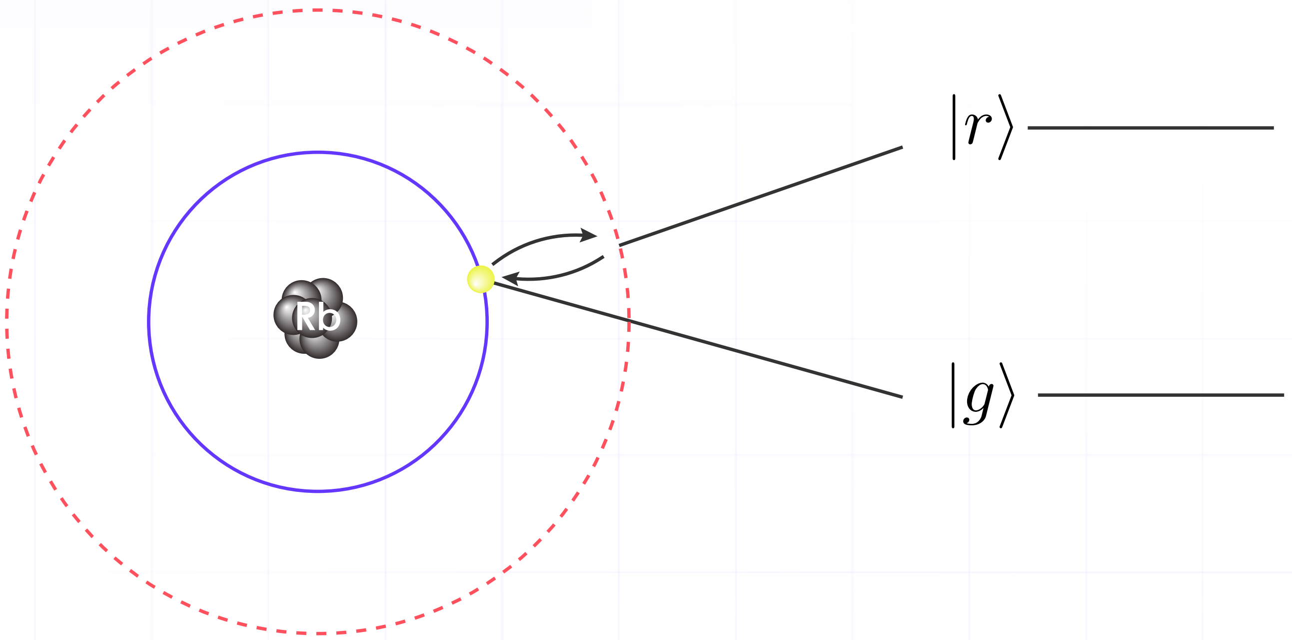
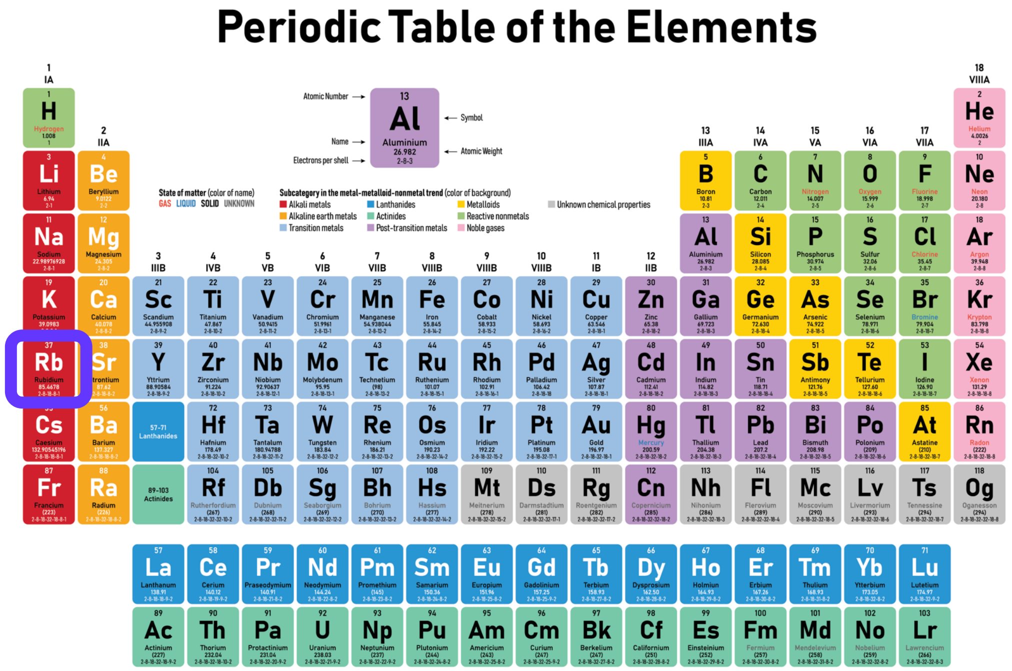
Learning objectives

By the end of the session, you will be able to:

- **Explain** how **neutral atoms** can be used as a **platform** for quantum computing
- **Distinguish** **analog** and **digital** (gate-based) quantum computing
- **Define** **field-programmable qubit arrays** and **exemplify** some of their **advantages**
- **Describe** Aquila's **programming** range
  - its Hamiltonian and controllable parameters, limitations of service

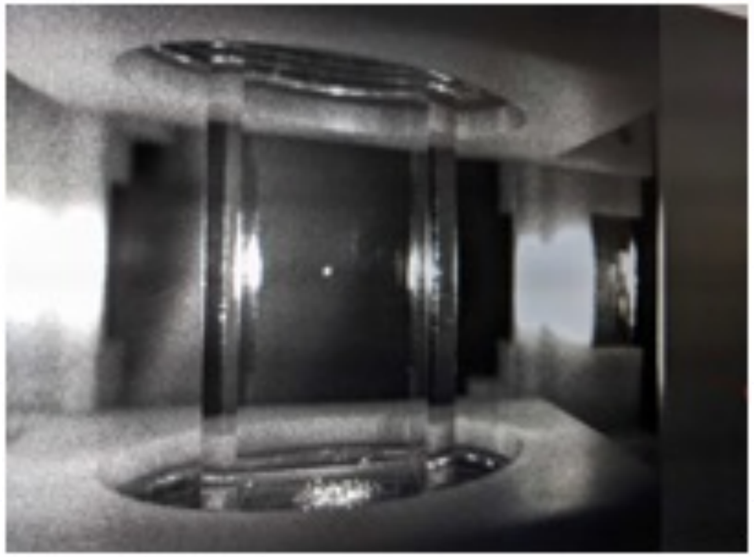
Qubits by puffing atoms

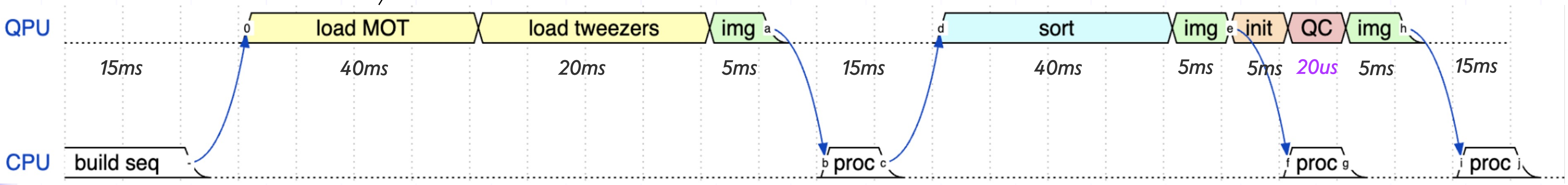




QPU cycle

~100k atoms
in a Rb-87 MOT





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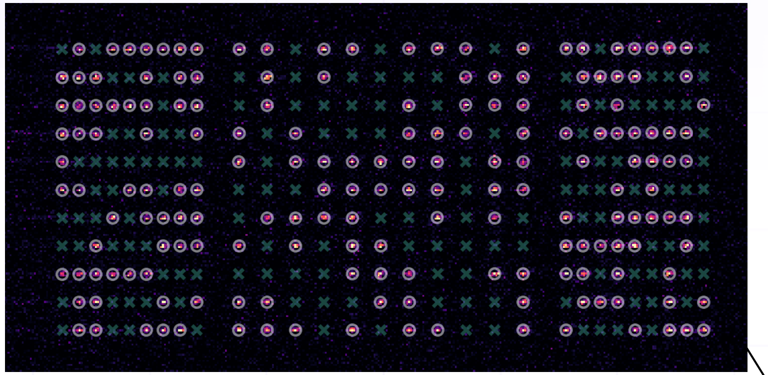
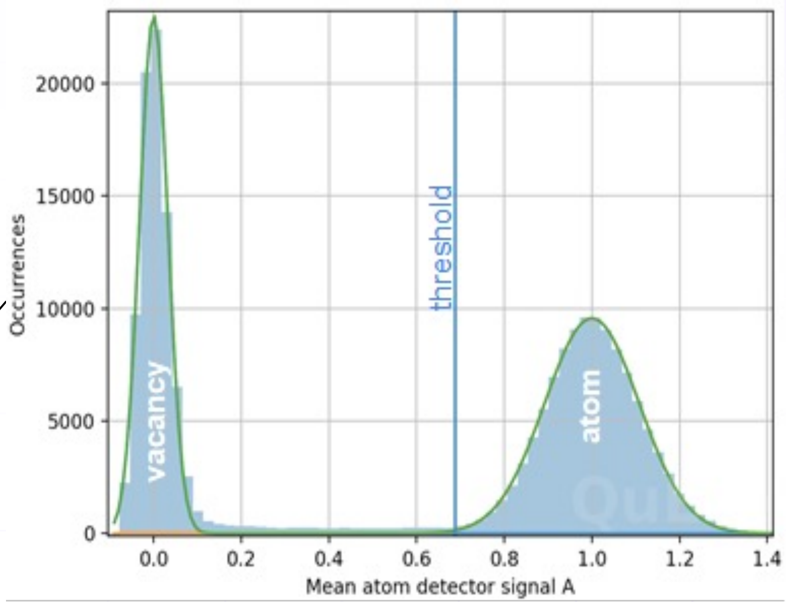
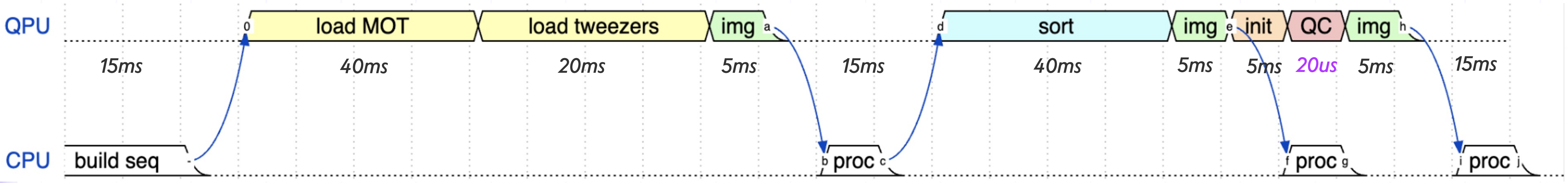
QPU cycle



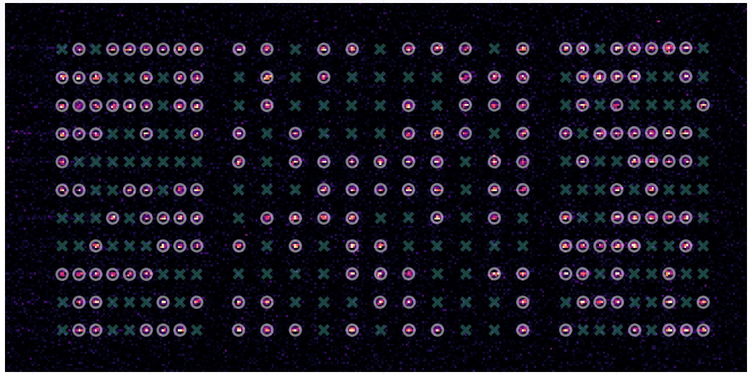
Loading occupation ~60%

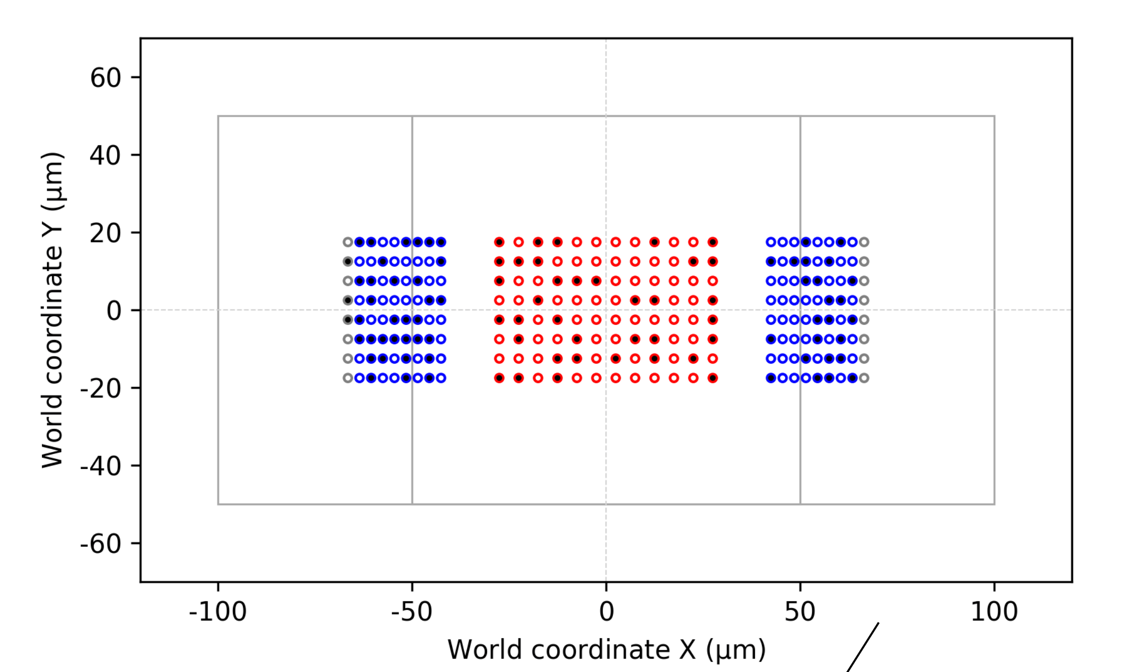
Atom detection 99.9%



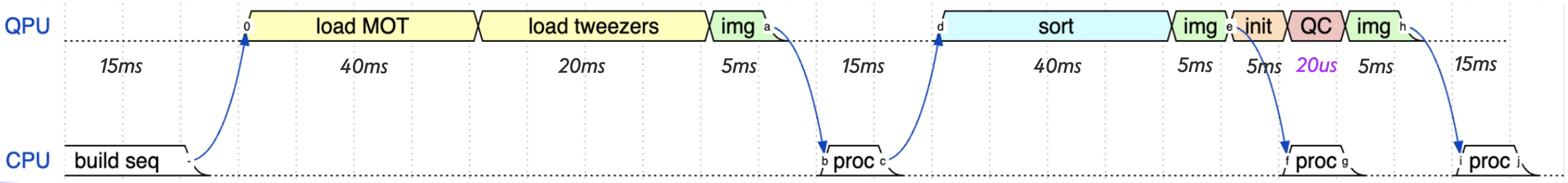


QPU cycle

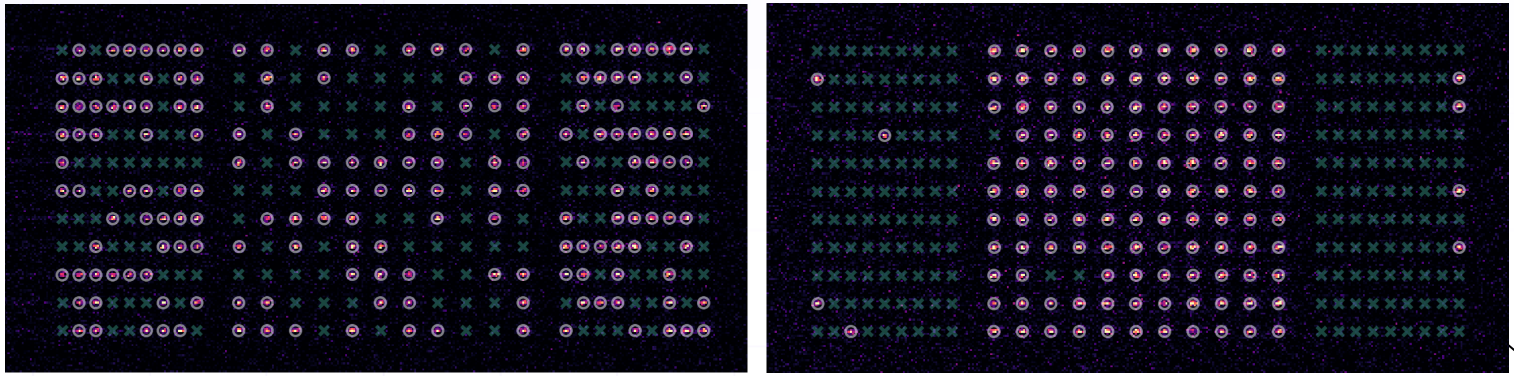




Rearrangement fidelity 99.5% / atom

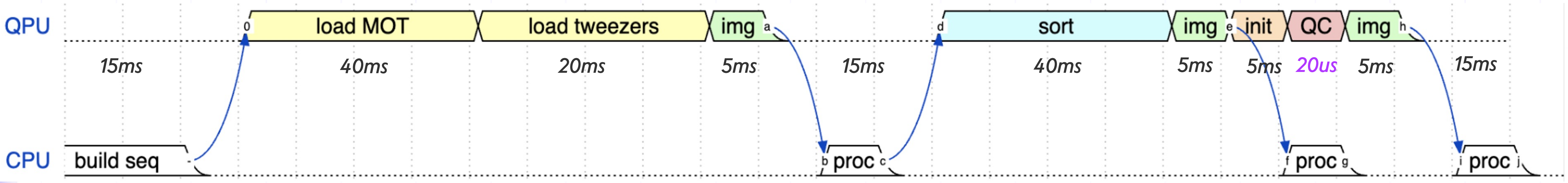


QPU cycle

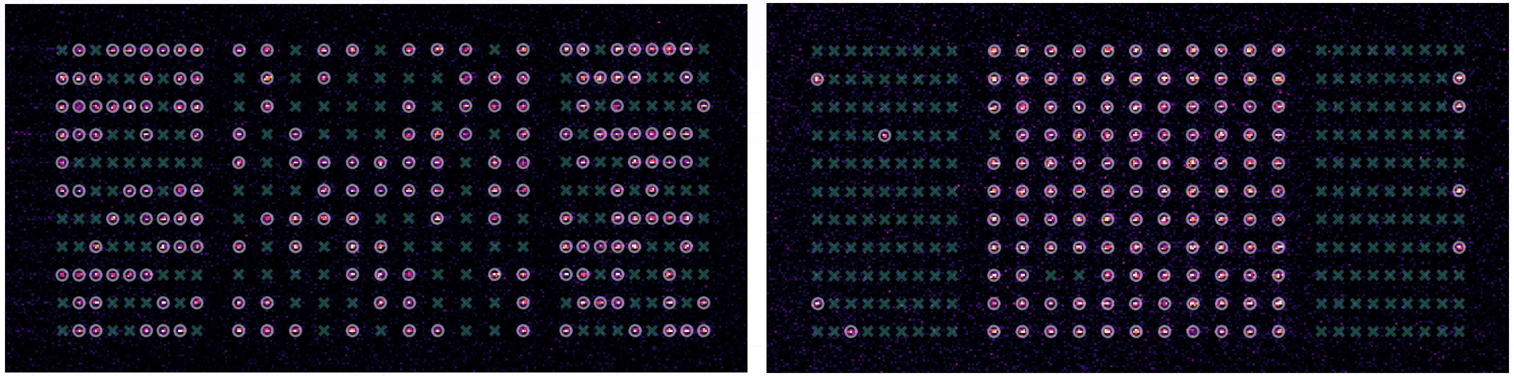


Rearrangement fidelity 99.5% / atom

Atom detection 99.9%

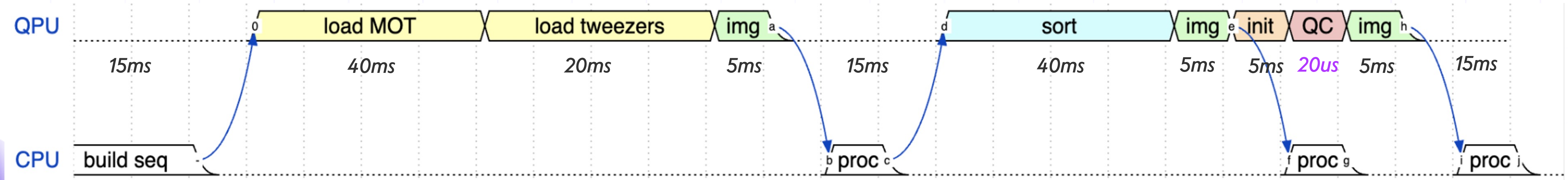


QPU cycle

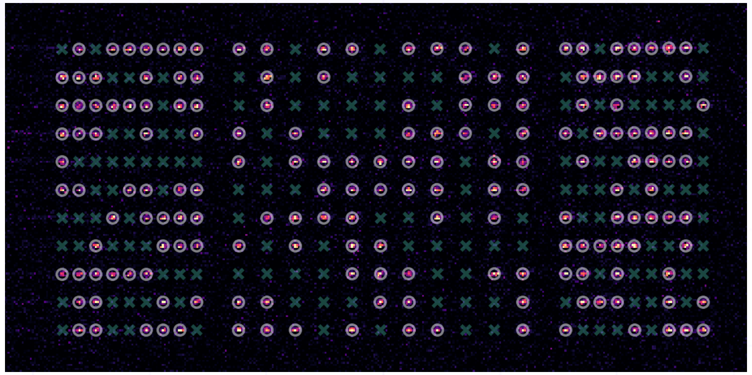
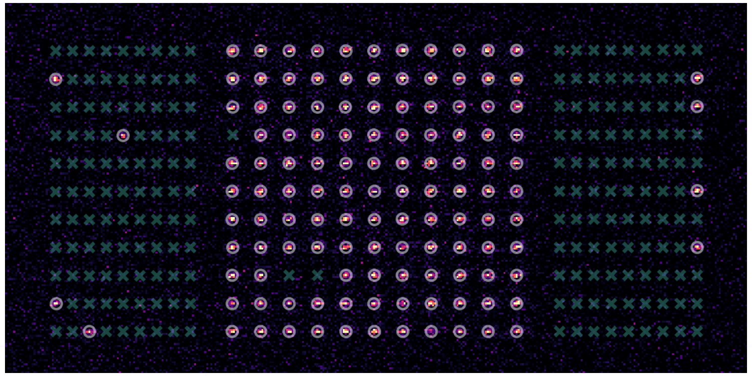


Cooling to
<10uk

Optical pumping
> 99%

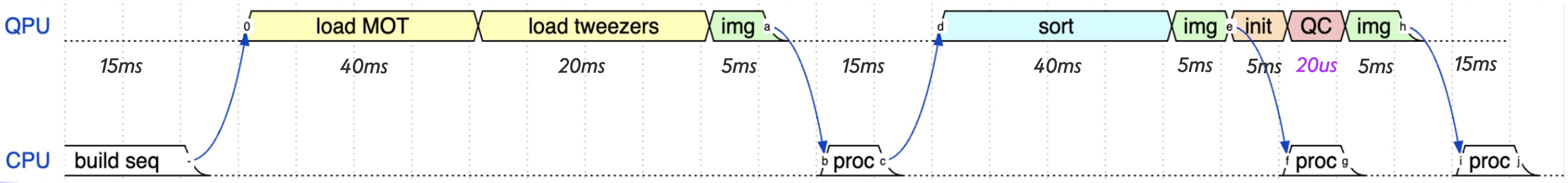


QPU cycle

Coherent evolution

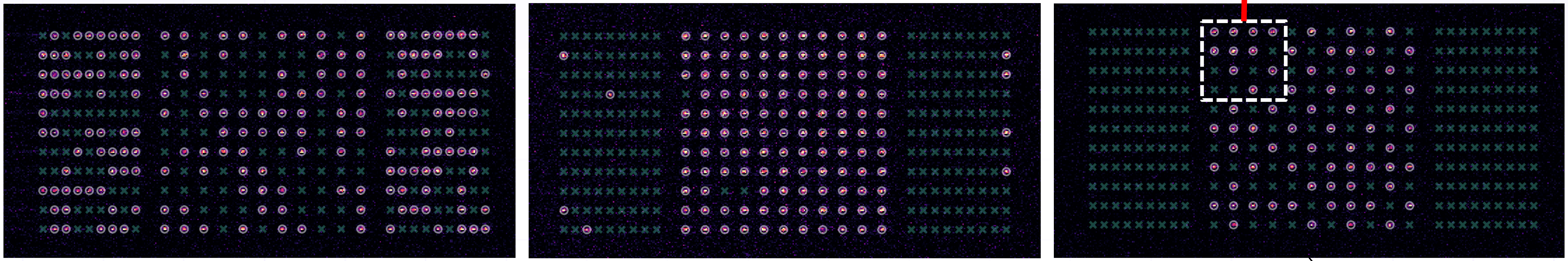
$$i\frac{\partial}{\partial t}|\psi\rangle = H|\psi\rangle$$

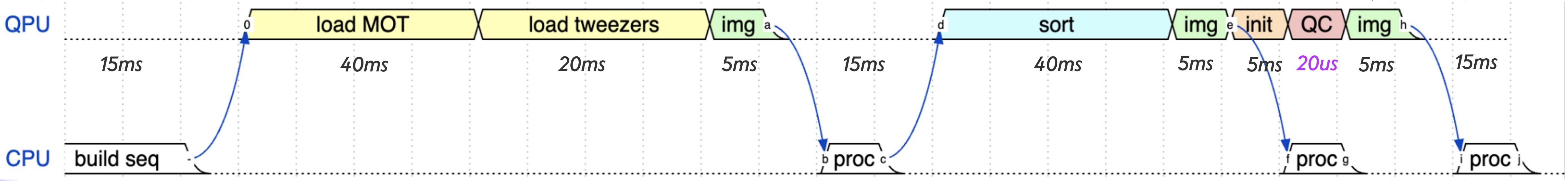


QPU cycle

```
[[1, 1, 1, 1
 [1, 1, 1, 0
 [0, 1, 0, 1
 [0, 0, 1, 0
```

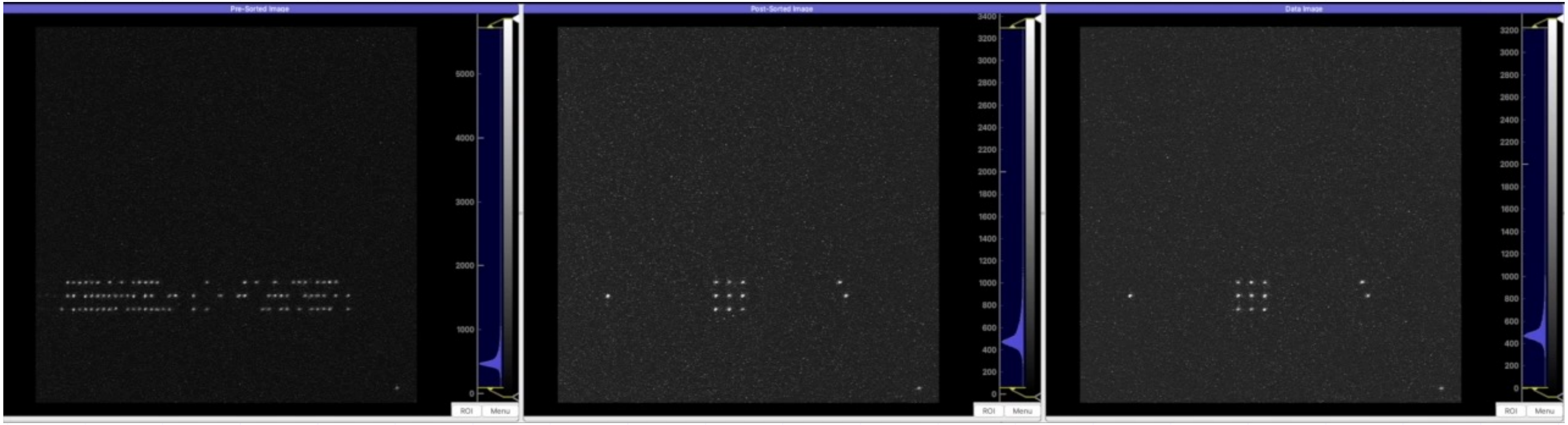
State detection > 95%





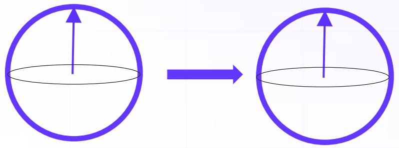
Sneak peak into the running engine

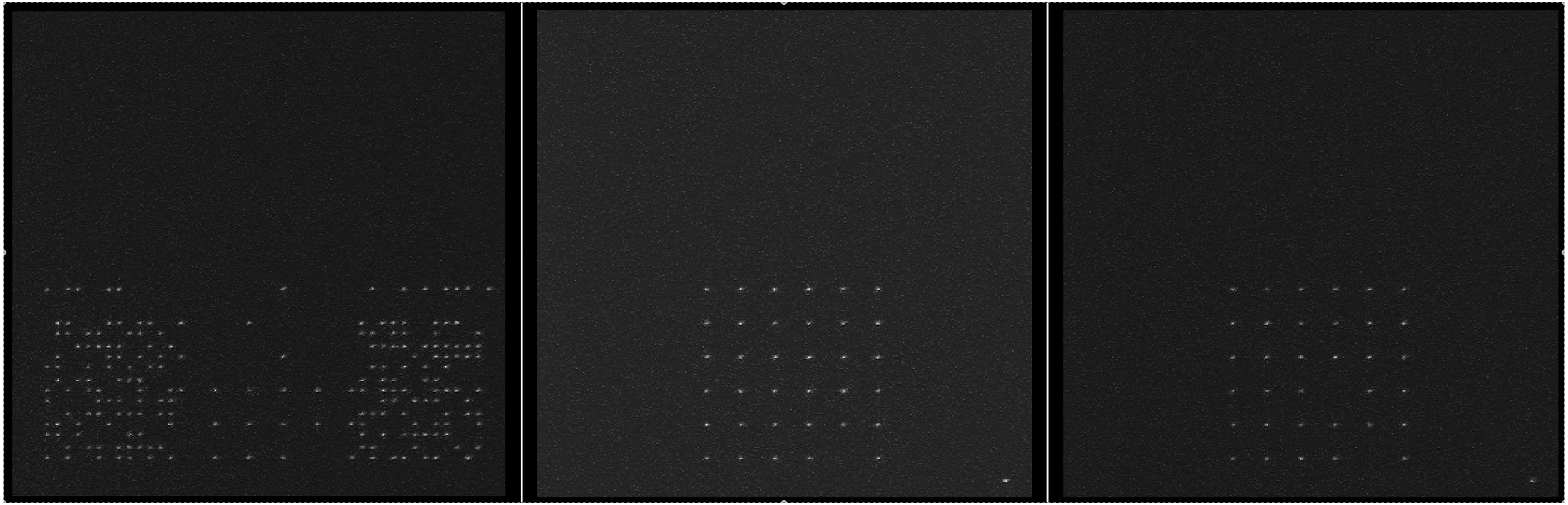
Sneak peak into the running engine



What qubit control really looks like:

2π pulse





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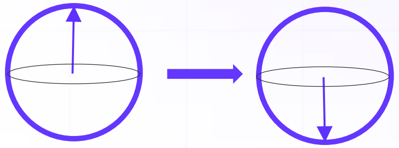
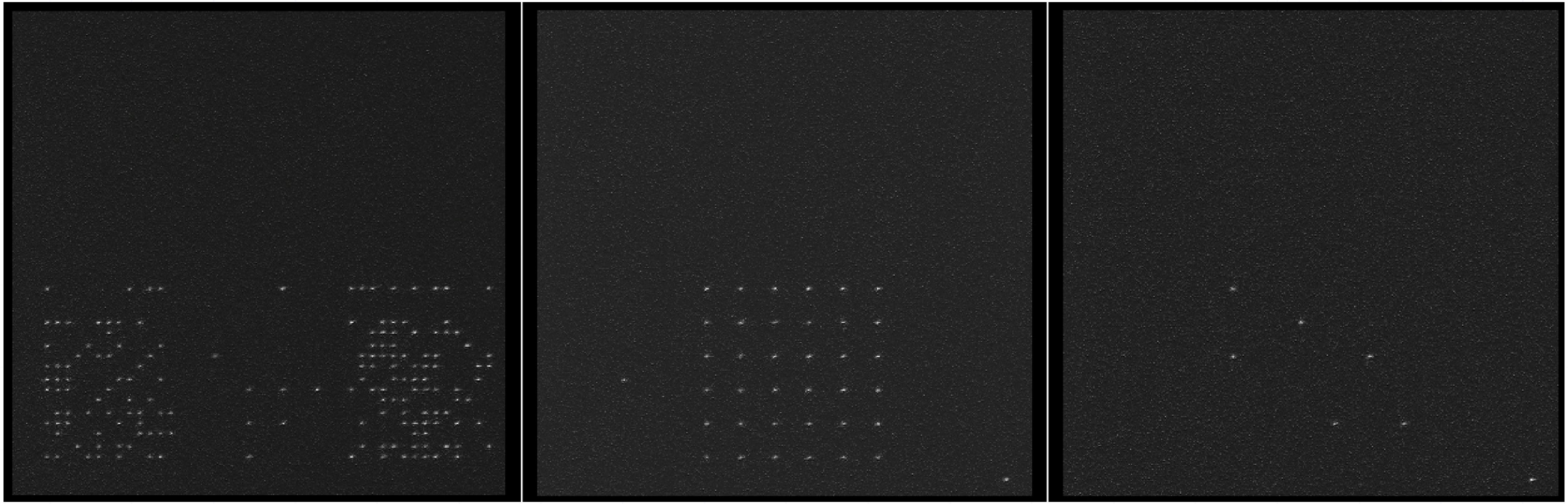
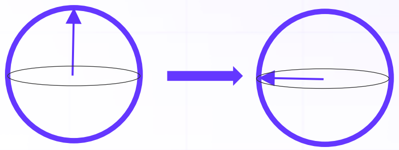
π pulse

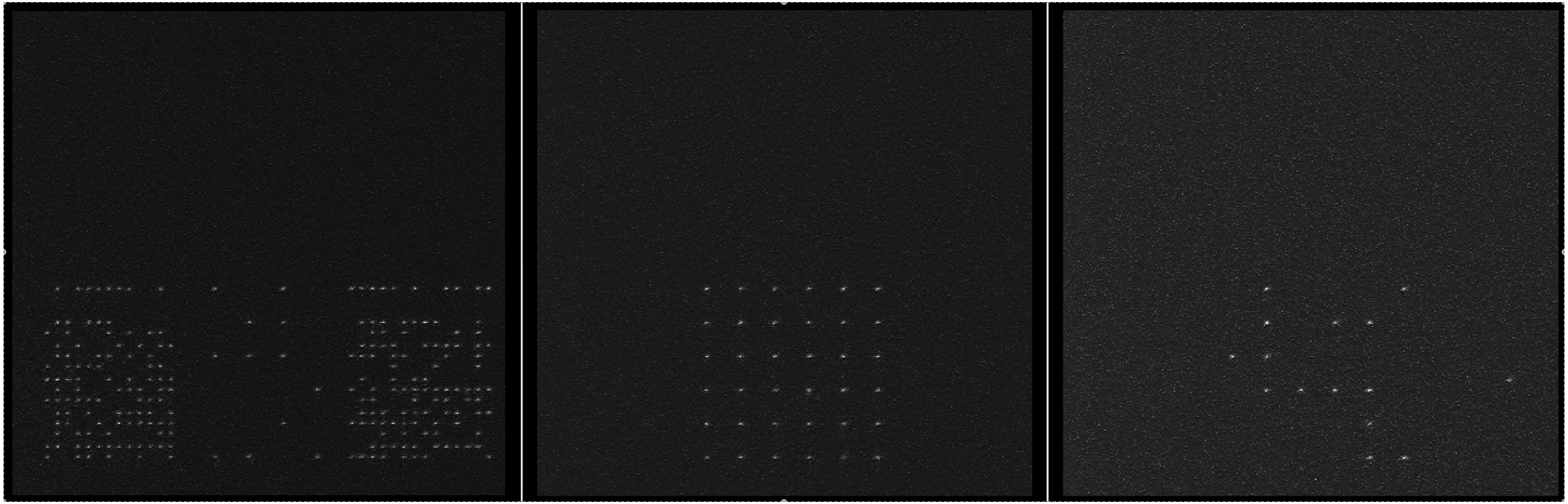




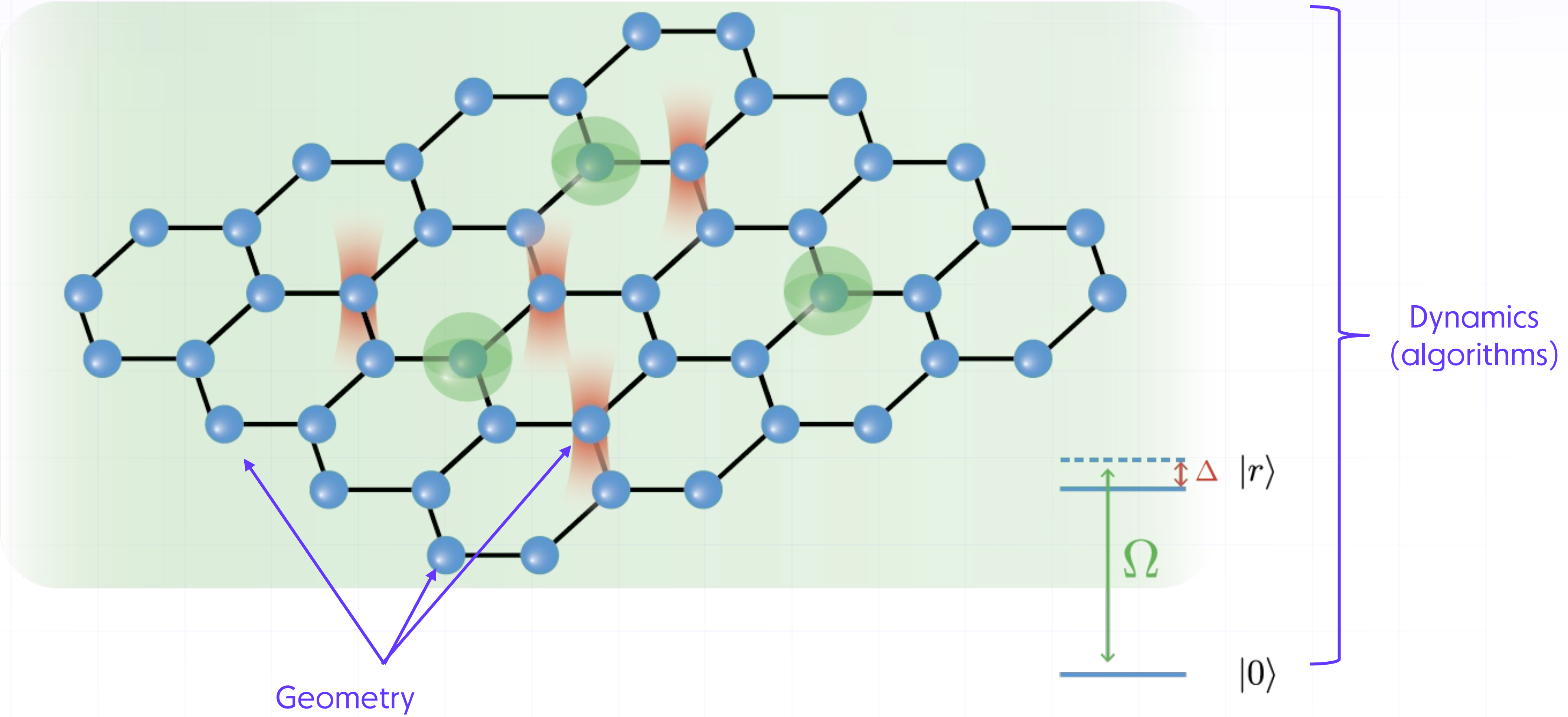
What qubit control really looks like:

$\pi/2$ *pulse*

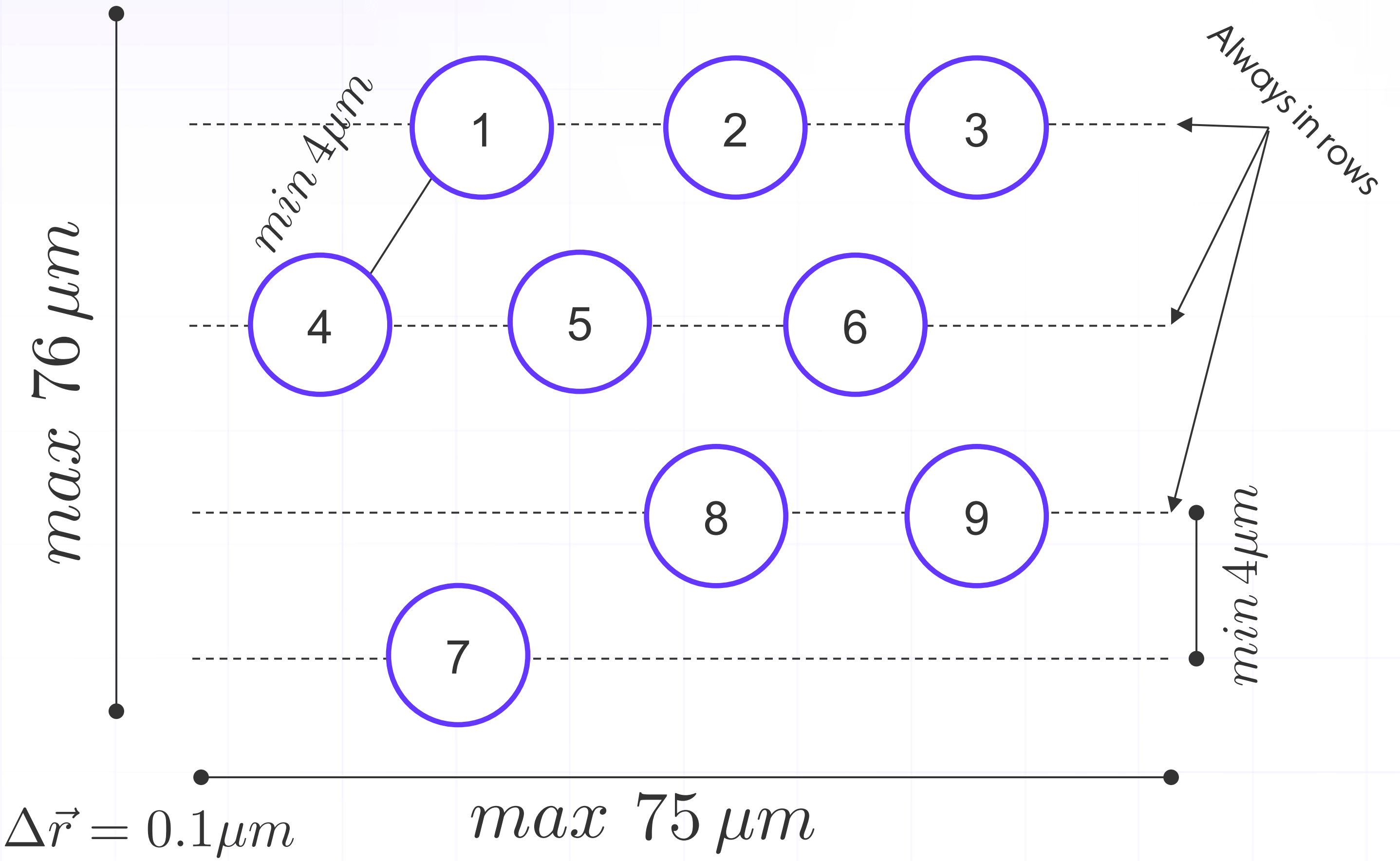




A neutral-atom quantum processor



Hardware constraints: Geometry



$\Delta\vec{r} = 0.1\mu m$

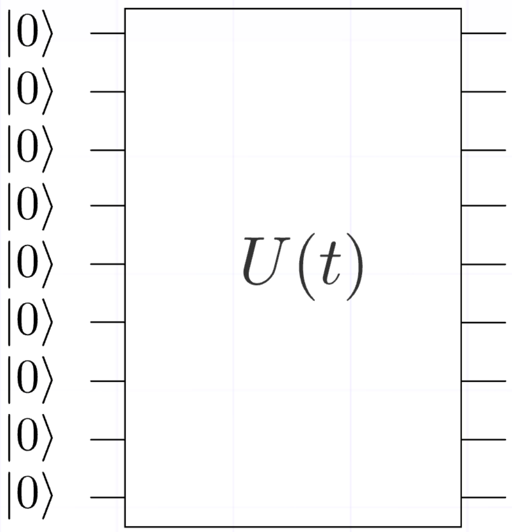
Activity 1:
Think-pair-share. What do you think is the origin of each of these constraints?

Activity 2:
defining qubit positions on Bloqade

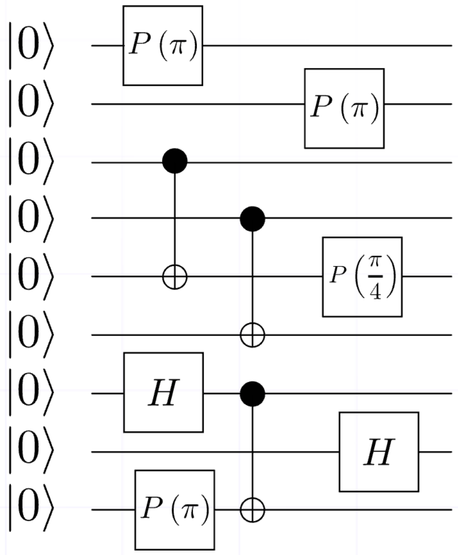
More details @
https://queracomputing.github.io/Bloqade.jl/dev/capabilities/

Information processing: Analog computing

Analog operation



Digital operation



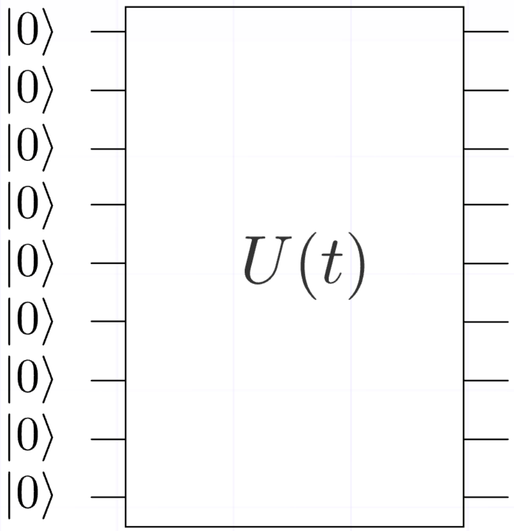
Designed for the early stage of maturity of the quantum computing resources of today…

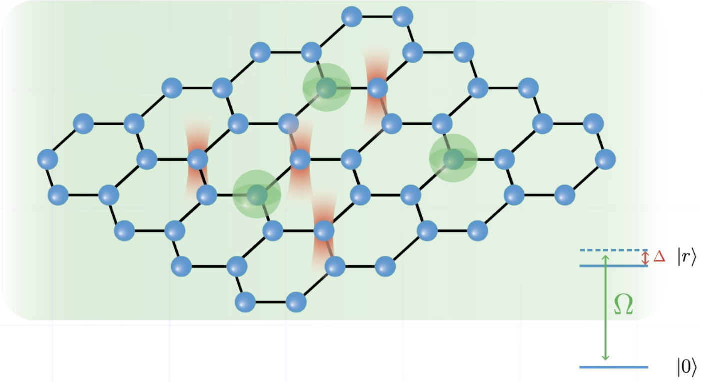
- ✓ Robustness to errors
- ✓ Efficient control
- ✓ Single-step large entanglement
- ✗ Universal applicability

More on analog processors:
Nature **volume 607**, p. 667–676 (2022)

Field Programmable Qubit Arrays (FPQAs)

Analog operation





Control qubit positions! Control qubit connectivity!

$\Rightarrow$ Many possibilities!

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- Robustness to errors
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- ~~Universal applicability~~

More on analog processors:
Nature **volume 607**, p. 667–676 (2022)

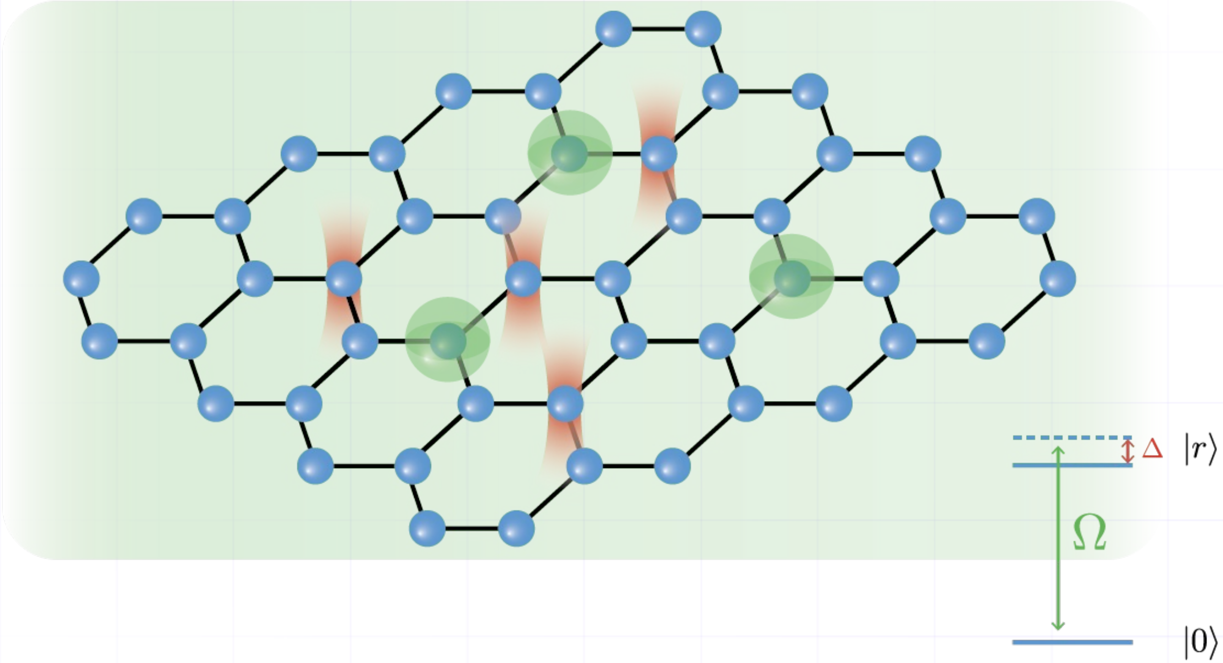
Algorithm = time evolution

$$i\frac{\partial}{\partial t}|\psi\rangle = \boxed{H}|\psi\rangle$$

|QuEra>

Analog quantum dynamics control

$$H = \sum_i \frac{\Omega(t)}{2}\left(e^{i\phi(t)}|g_i\rangle\langle r_i| + e^{-i\phi(t)}|r_i\rangle\langle g_i|\right) - \sum_i \Delta(t) n_i + \sum_{i<j} V_{ij} n_i n_j$$



$$n_i = 1 * |r_i\rangle\langle r_i| + 0 * |\mathrm{g}_i\rangle\langle \mathrm{g}_i|$$

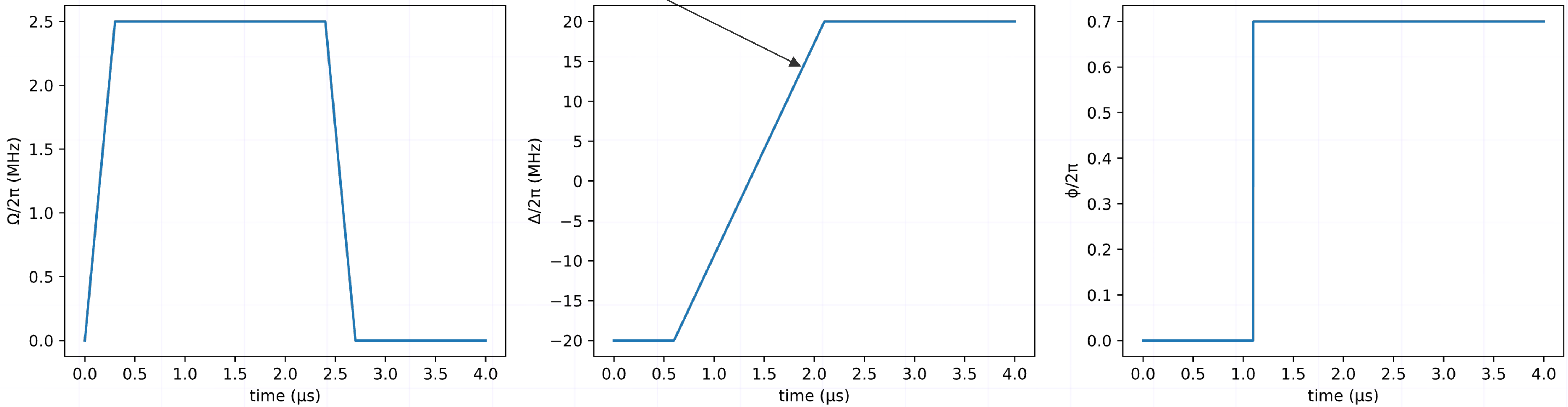
$$V_{ij} \sim d_{ij}^{-6}$$

Hardware constraints: dynamics

Activity: Encoding waveforms on Bloqade

Piecewise-linear

max max

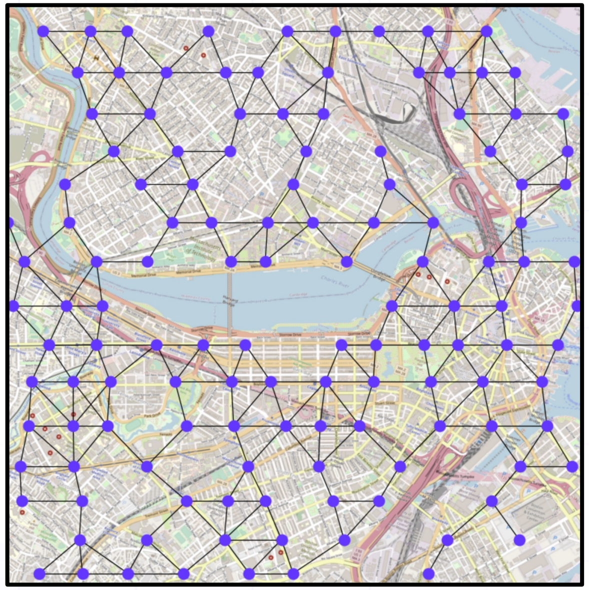


$$t_{max} = 4\mu s$$

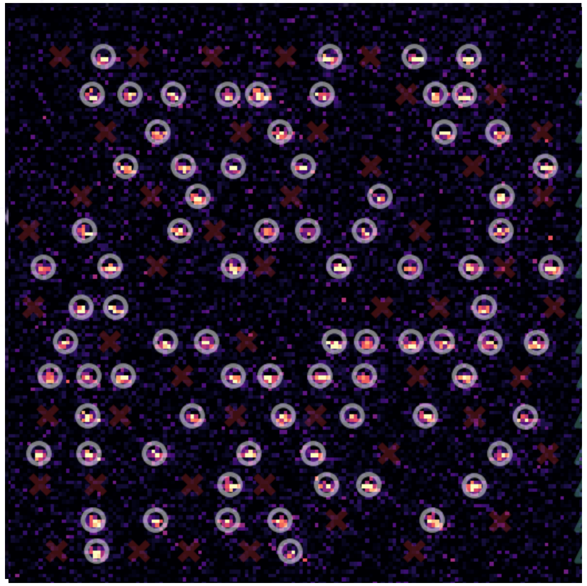
Piecewise-constant

FPQA = Efficient Problem Encoding

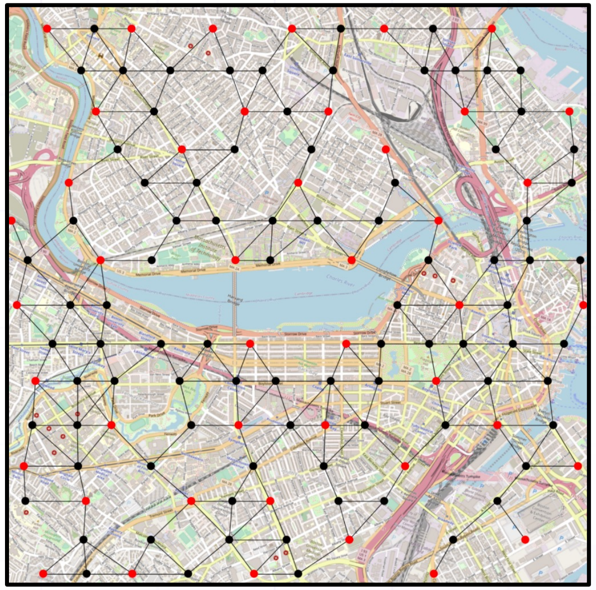
Choose possible locations



Create an atomic twin

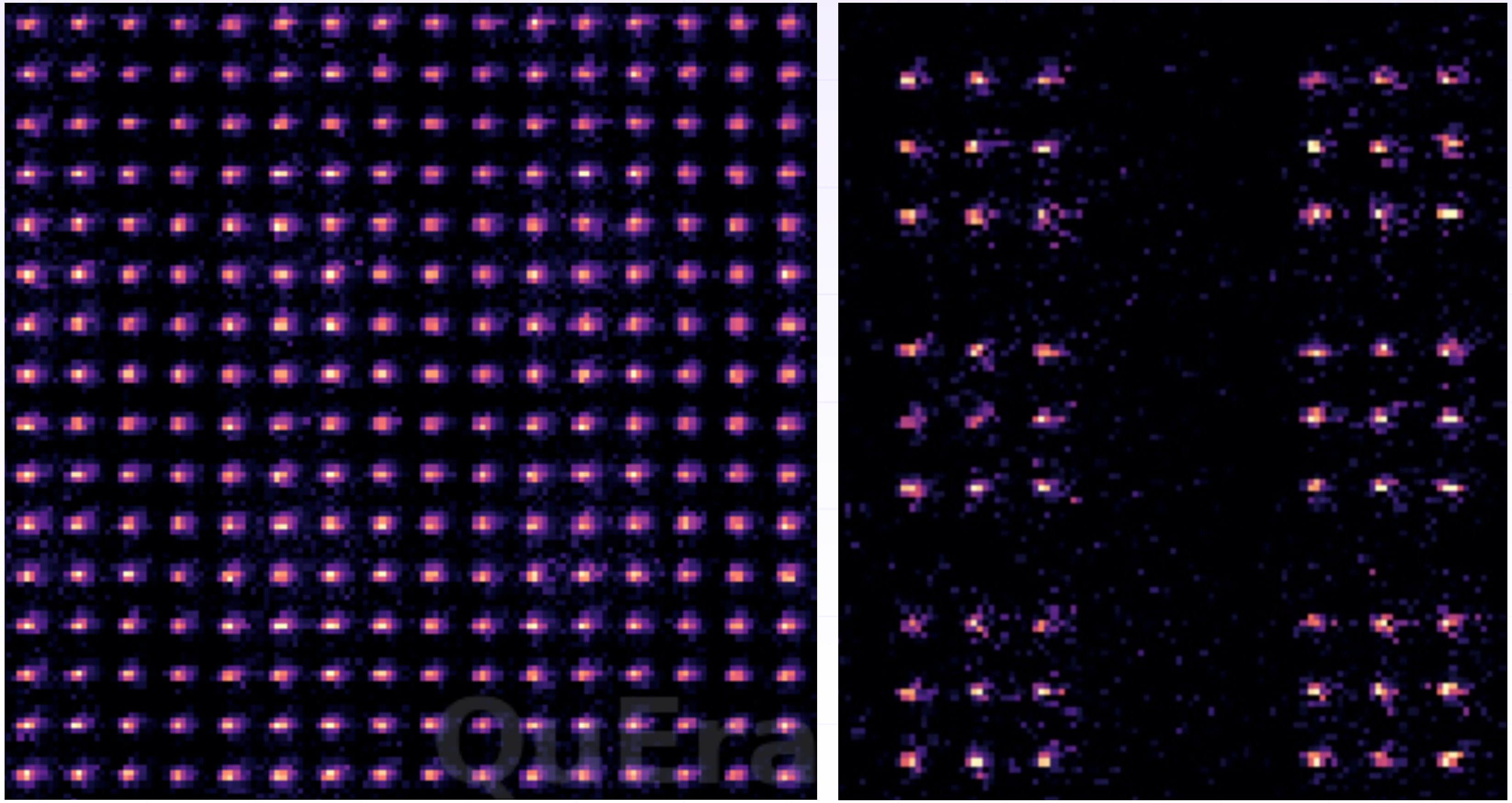


Excite atoms to find answer!



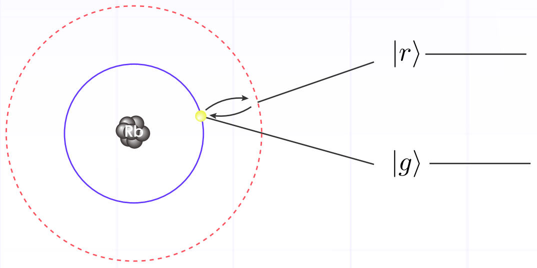
How to optimally cover Boston with coffee shops?

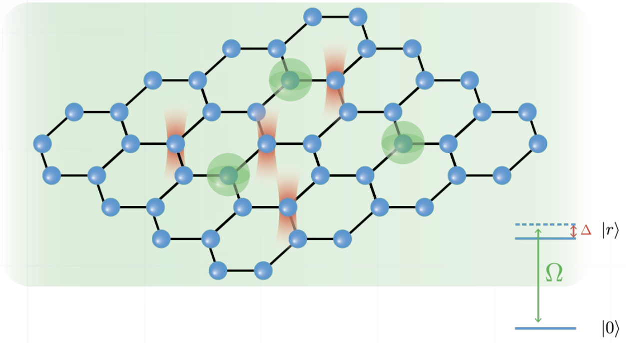
FPQA = Parallelization



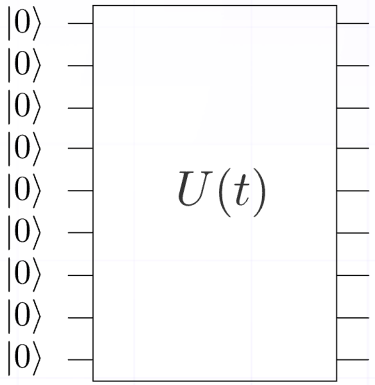
Summary

Architecture

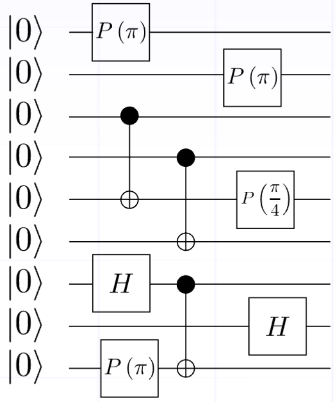




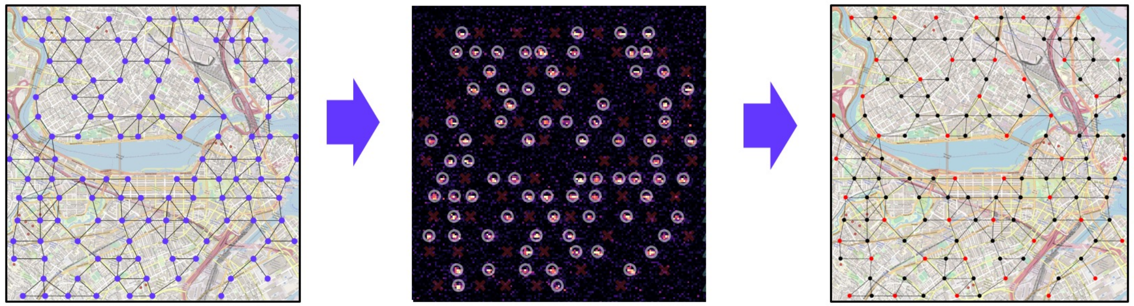
Analog operation



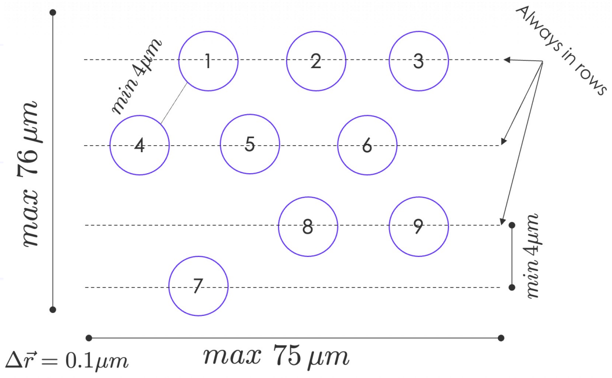
Digital operation

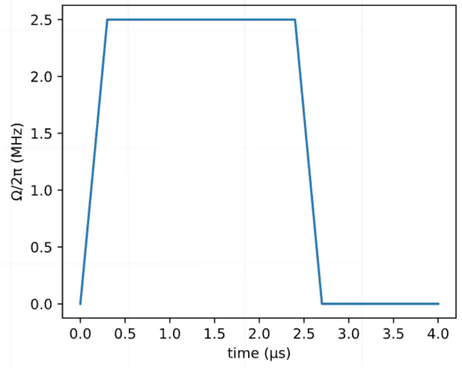


FPQA paradigm



Hardware constraints





Learning objectives

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