

IQuEra>

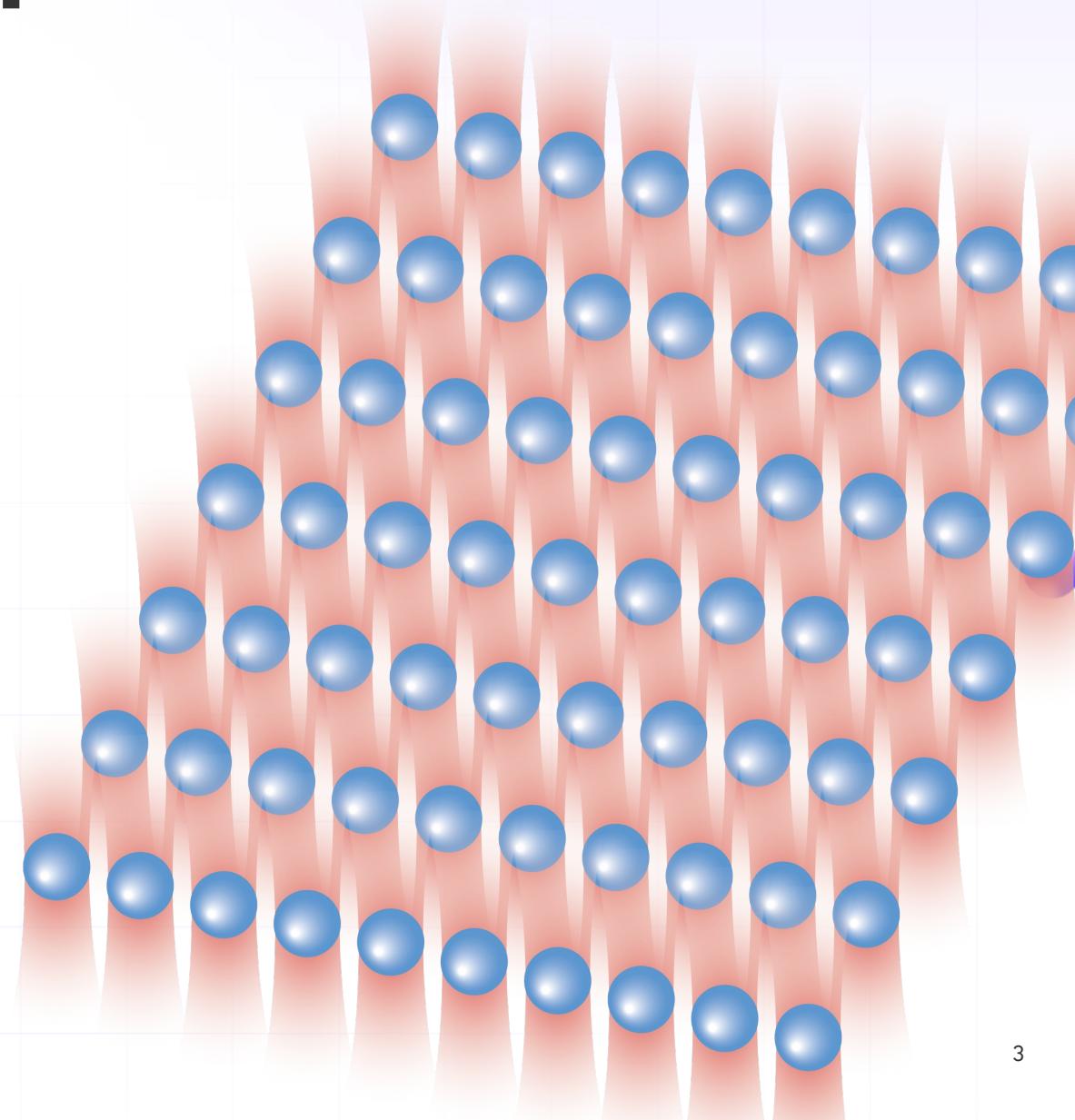
# Session I: Basics

# **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!

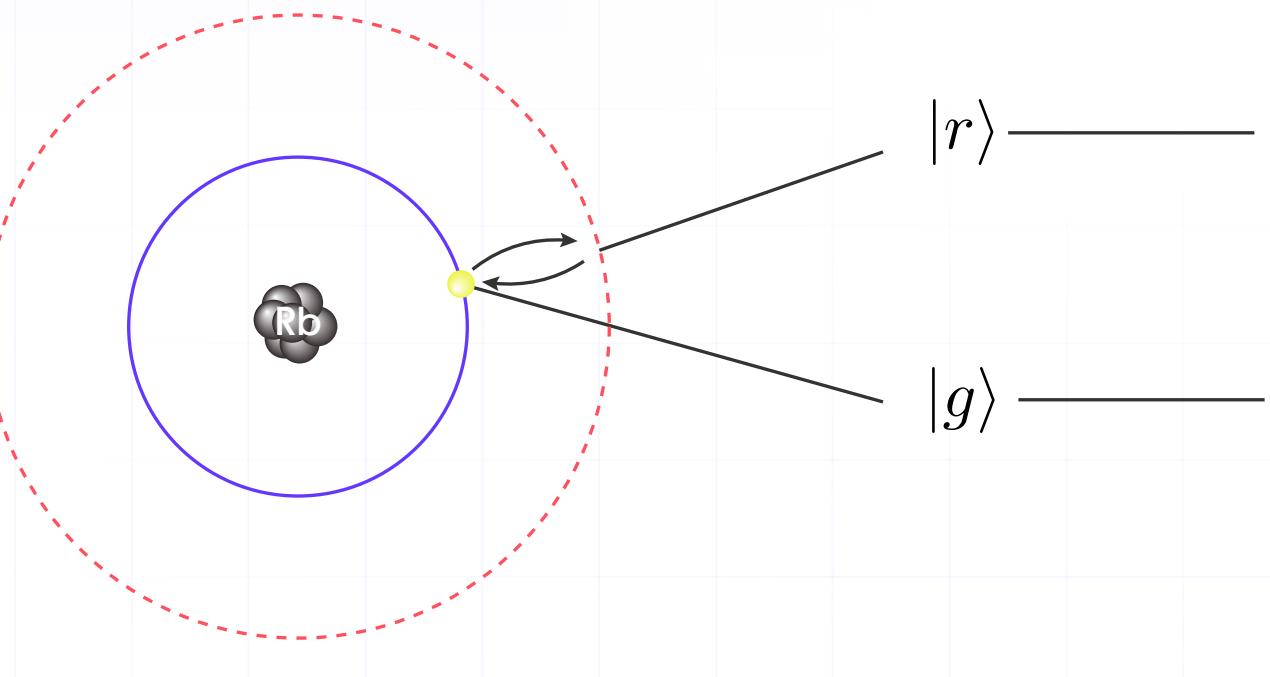


# Learning objectives

**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
- **Describe** Aquila's **programming** range
  - its Hamiltonian and controllable parameters, limitations of service

# Qubits by puffing atoms



Periodic Table of the Elements

Periodic Table of the Elements

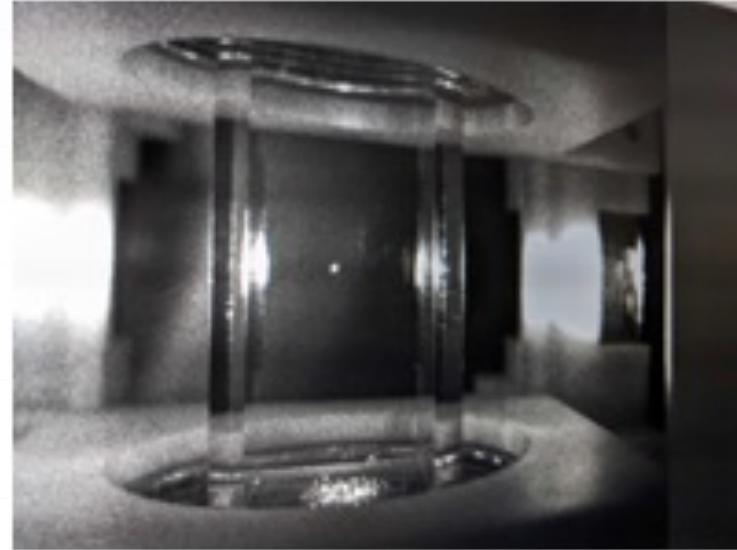
The table includes the following information for each element:

- Atomic Number**: The element's position in the periodic table.
- Symbol**: The standard two-letter symbol for the element.
- Name**: The element's name.
- Atomic Weight**: The element's mass number.
- Electrons per shell**: The number of electrons in each shell, represented by a sequence of numbers (e.g., 2, 8, 8, 2 for Helium).
- State of matter [color of name]**: The element's state of matter at room temperature and its color.
- Subcategory in the metal-metalloid-nonmetal trend (color of background)**: Categories include Alkali metals (red), Alkaline earth metals (blue), Lanthanides (light blue), Actinides (pink), Transition metals (yellow), Post-transition metals (orange), Metalloids (green), Nonmetals (purple), and Noble gases (pink).
- Unknown chemical properties**: Indicated by a grey question mark icon.

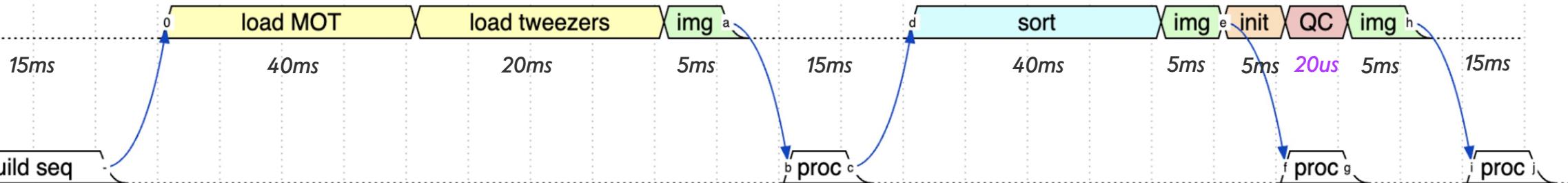
Atomic Number	Symbol	Name	Atomic Weight	Electrons per shell	State of matter [color of name]	Subcategory in the metal-metalloid-nonmetal trend (color of background)	Unknown chemical properties
1	H	Hydrogen	1.008	1	GAS	Alkali metals	
2	He	Helium	4.003	2	LIQUID	Alkaline earth metals	
3	Li	Lithium	6.941	2, 1	SOLID	Lanthanides	
4	Be	Beryllium	9.012	2, 2		Actinides	
5	B	Boron	10.81	2, 3		Transition metals	
6	C	Carbon	12.011	2, 4		Post-transition metals	
7	N	Nitrogen	14.007	2, 5		Metalloids	
8	O	Oxygen	15.999	2, 6		Nonmetals	
9	F	Fluorine	18.998	2, 7		Noble gases	
10	Ne	Neon	20.180	2, 8			
11	Na	Sodium	22.989	2, 8, 1			
12	Mg	Magnesium	24.305	2, 8, 2			
13	Al	Aluminum	26.981	2, 8, 3			
14	Si	Silicon	28.085	2, 8, 4			
15	P	Phosphorus	30.973	2, 8, 5			
16	S	Sulfur	32.065	2, 8, 6			
17	Cl	Chlorine	35.45	2, 8, 7			
18	Ar	Argon	39.948	2, 8, 8			
19	K	Potassium	39.092	2, 8, 1, 1			
20	Ca	Calcium	40.078	2, 8, 2, 1			
21	Sc	Scandium	44.955	2, 8, 2, 1			
22	Ti	Titanium	47.867	2, 8, 2, 2			
23	V	Vanadium	50.941	2, 8, 3, 1			
24	Cr	Chromium	51.996	2, 8, 3, 2			
25	Mn	Manganese	54.938	2, 8, 3, 2			
26	Fe	Iron	55.845	2, 8, 4, 1			
27	Co	Cobalt	58.933	2, 8, 4, 2			
28	Ni	Nickel	58.693	2, 8, 4, 2			
29	Cu	Copper	63.546	2, 8, 5, 1			
30	Zn	Zinc	65.401	2, 8, 5, 2			
31	Ga	Gallium	69.723	2, 8, 5, 3			
32	Ge	Germanium	72.610	2, 8, 5, 3			
33	As	Arsenic	74.924	2, 8, 6, 1			
34	Se	Selenium	78.911	2, 8, 6, 2			
35	Br	Bromine	80.912	2, 8, 6, 2			
36	Kr	Krypton	83.813	2, 8, 8, 2			
37	Rb	Rubidium	85.461	2, 8, 8, 2			
38	Sr	Samarium	87.612	2, 8, 8, 2			
39	Y	Yttrium	88.905	2, 8, 8, 2			
40	Zr	Zirconium	91.224	2, 8, 8, 2			
41	Nb	Niobium	92.906	2, 8, 8, 2			
42	Mo	Molybdenum	95.941	2, 8, 8, 2			
43	Tc	Technetium	(97)	2, 8, 8, 1			
44	Ru	Ruthenium	102	2, 8, 8, 2			
45	Rh	Rhenium	102	2, 8, 8, 2			
46	Pd	Palladium	106.4	2, 8, 8, 2			
47	Ag	Silver	107.87	2, 8, 8, 2			
48	Cd	Cadmium	112.4	2, 8, 8, 2			
49	In	Inertium	114.82	2, 8, 8, 2			
50	Sb	Sulfur	118.71	2, 8, 8, 2			
51	Te	Technetium	121.74	2, 8, 8, 2			
52	I	Iodine	127.60	2, 8, 8, 2			
53	Xe	Xenon	131.29	2, 8, 8, 2			
54	Rn	Radon	(220)	2, 8, 8, 2			
55	Cs	Cesium	132.911	2, 8, 8, 2			
56	Ba	Barium	137.32	2, 8, 8, 2			
57	La	Lanthanum	138.912	2, 8, 8, 2			
58	Ce	Cerium	140.113	2, 8, 8, 2			
59	Pr	Praseodymium	140.914	2, 8, 8, 2			
60	Nd	Neodymium	144.242	2, 8, 8, 2			
61	Pm	Promethium	(147)	2, 8, 8, 2			
62	Sm	Samarium	150.843	2, 8, 8, 2			
63	Eu	Europeum	151.943	2, 8, 8, 2			
64	Gd	Gadolinium	157.251	2, 8, 8, 2			
65	Dy	Dysprosium	160.943	2, 8, 8, 2			
66	Tb	Terbium	161.943	2, 8, 8, 2			
67	Ho	Holmium	164.943	2, 8, 8, 2			
68	Er	Erbium	167.251	2, 8, 8, 2			
69	Tm	Thulium	168.943	2, 8, 8, 2			
70	Yb	Ytterbium	173.043	2, 8, 8, 2			
71	Lu	Lutetium	174.943	2, 8, 8, 2			
72	Ac	Actinium	(227)	2, 8, 8, 2			
73	Th	Thorium	232.04	2, 8, 8, 2			
74	Pa	Protactinium	231.04	2, 8, 8, 2			
75	U	Uranium	238.03	2, 8, 8, 2			
76	Np	Neptunium	(237)	2, 8, 8, 2			
77	Pu	Plutonium	(240)	2, 8, 8, 2			
78	Am	Americium	(243)	2, 8, 8, 2			
79	Cm	Curium	(247)	2, 8, 8, 2			
80	Bk	Berkelium	(247)	2, 8, 8, 2			
81	Cf	Californium	(250)	2, 8, 8, 2			
82	Es	Einsteinium	(257)	2, 8, 8, 2			
83	Fm	Magnesium	(259)	2, 8, 8, 2			
84	Md	Mendelevium	(259)	2, 8, 8, 2			
85	Rs	Rutherfordium	(261)	2, 8, 8, 2			
86	At	Astatine	(260)	2, 8, 8, 2			
87	Rn	Radon	(220)	2, 8, 8, 2			
88	Og	Oganesson	(264)	2, 8, 8, 2			

# QPU cycle

*~100k atoms  
in a Rb-87 MOT*

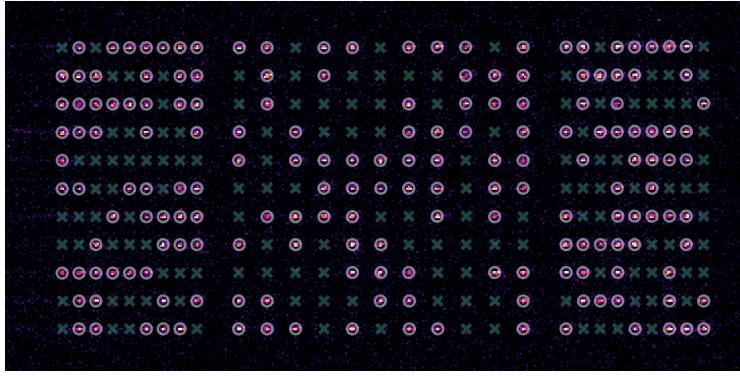


QPU



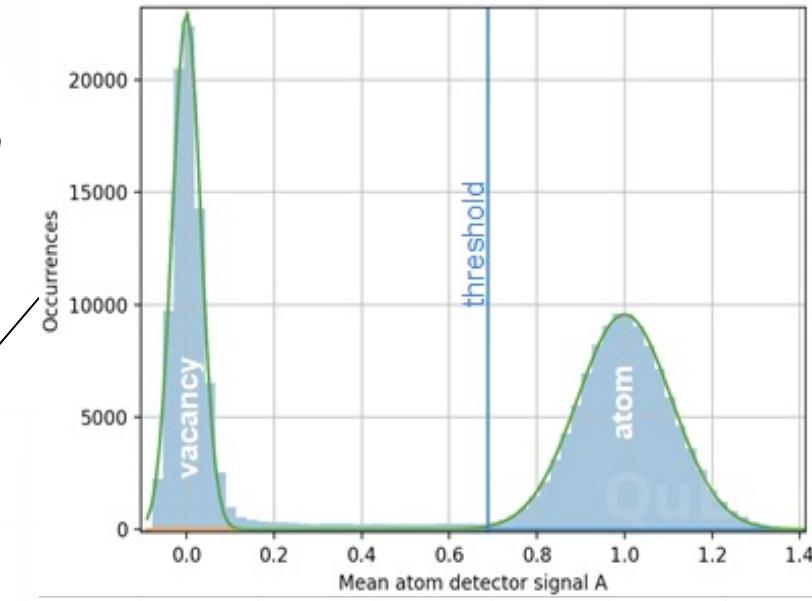
IQUERA >

# QPU cycle

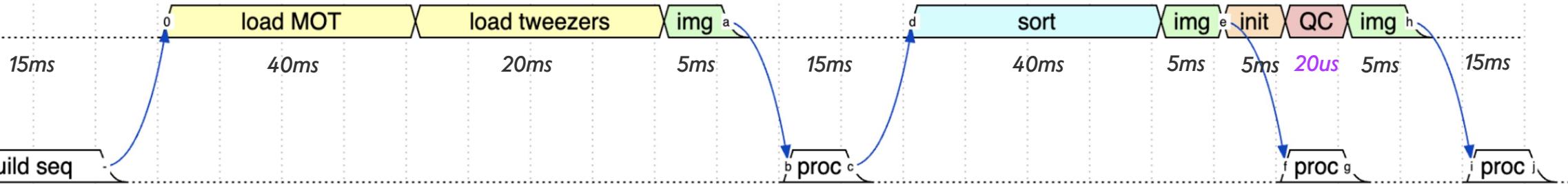


*Loading  
occupation  
~60%*

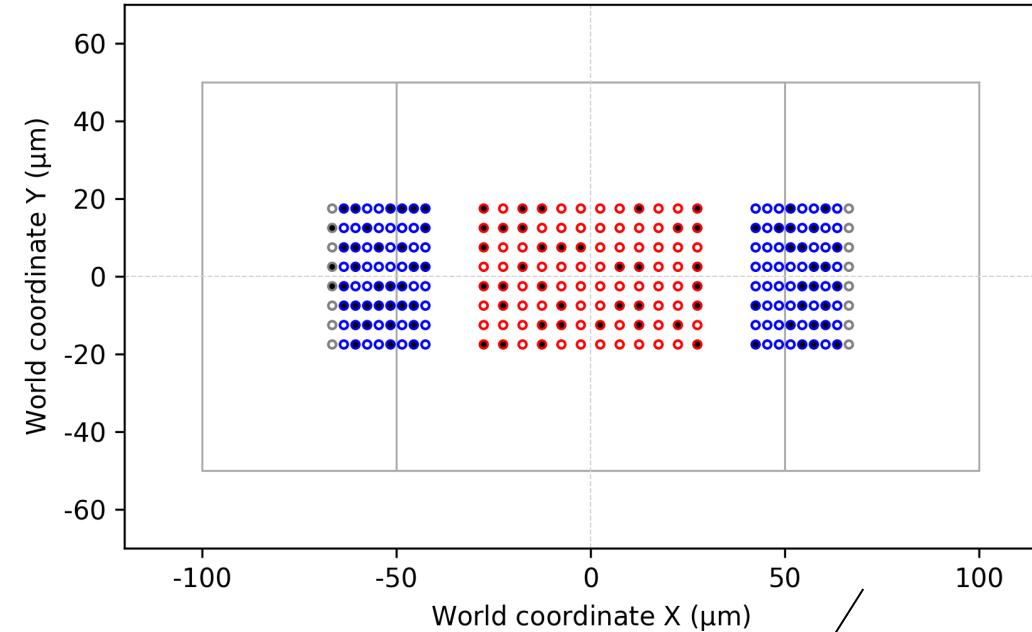
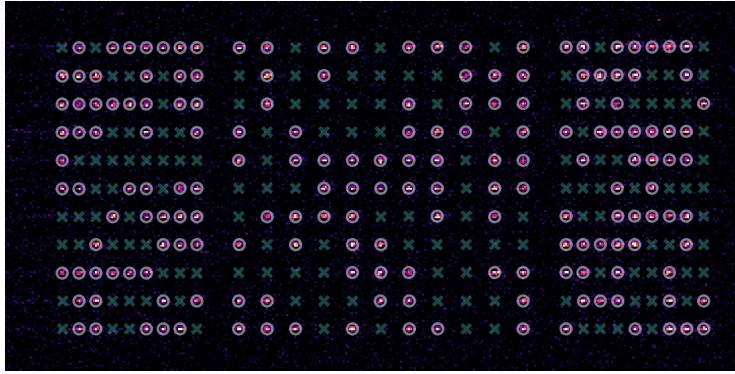
*Atom  
detection  
99.9%*



QPU

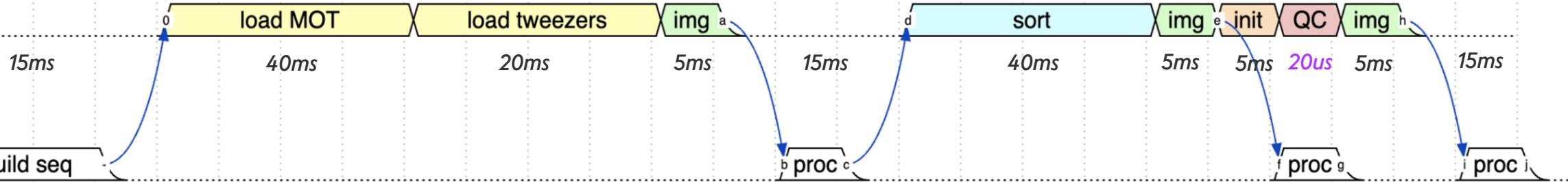


# QPU cycle



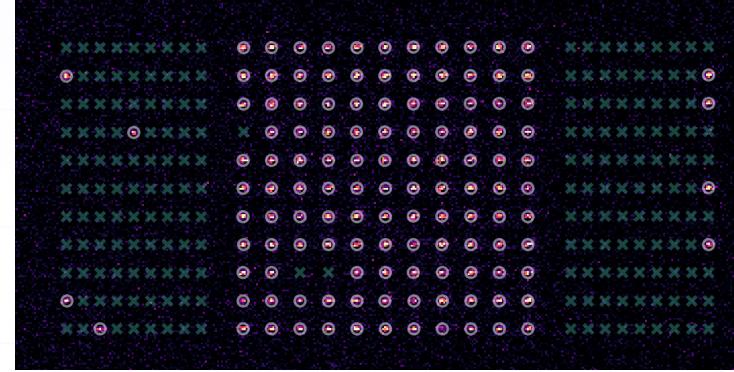
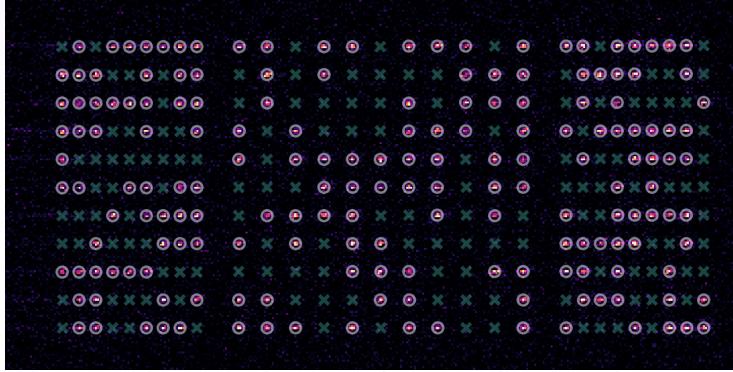
Rearrangement fidelity  
99.5% / atom

QPU



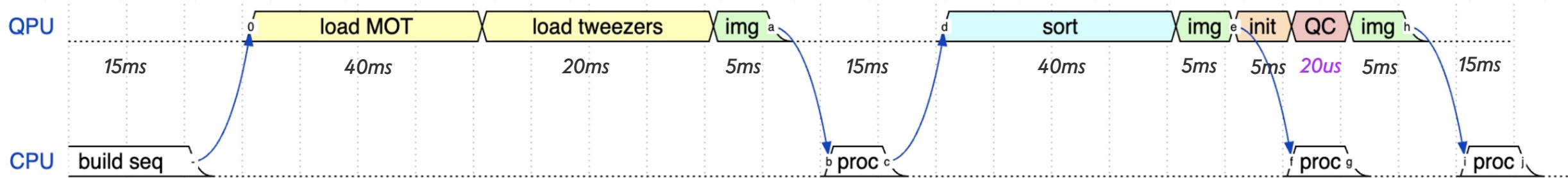
IQUERA >

# QPU cycle

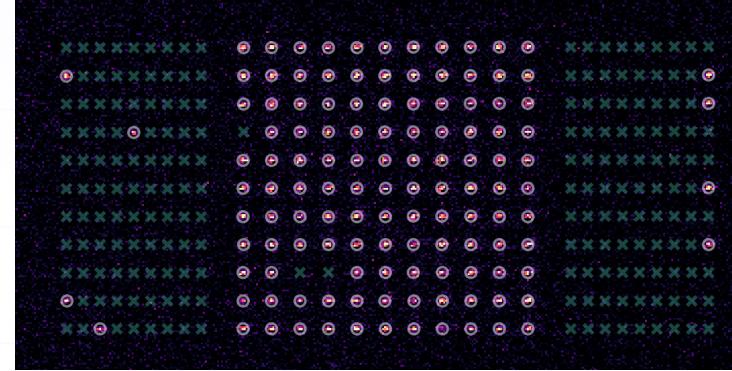
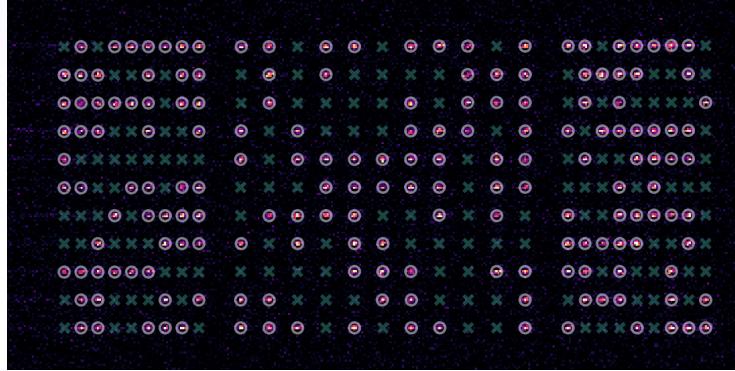


Rearrangement fidelity  
99.5% / atom

Atom detection  
99.9%

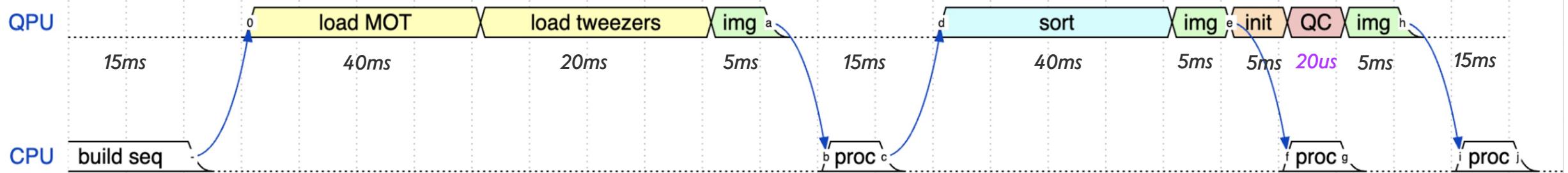


# QPU cycle

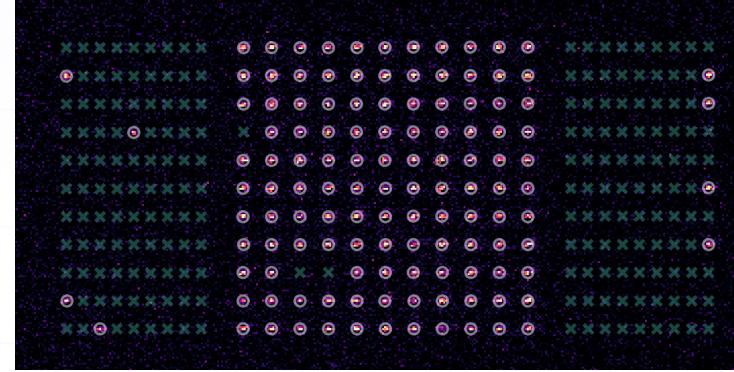
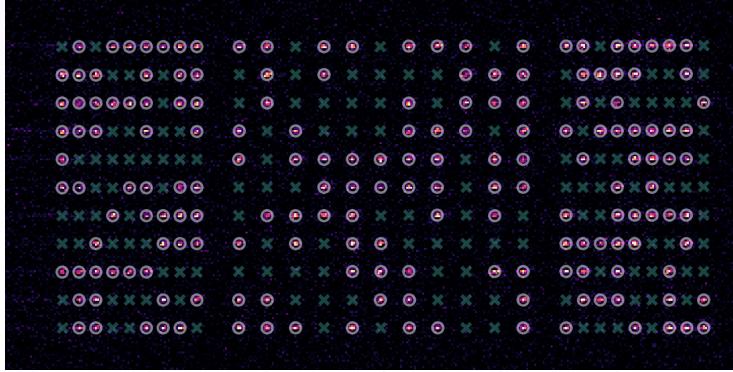


Cooling to  
 $<10\text{uk}$

Optical pumping  
 $> 99\%$

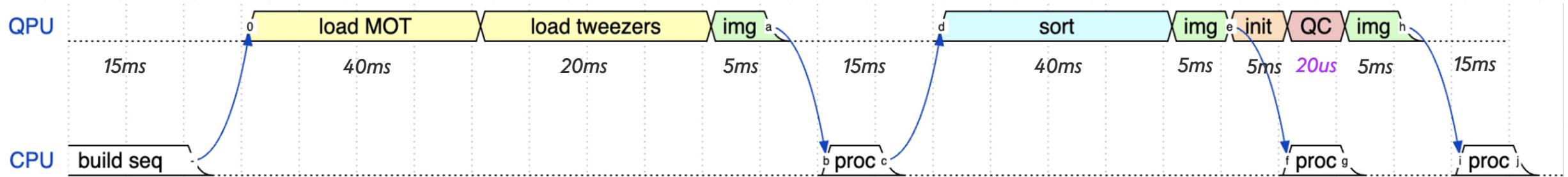


# QPU cycle

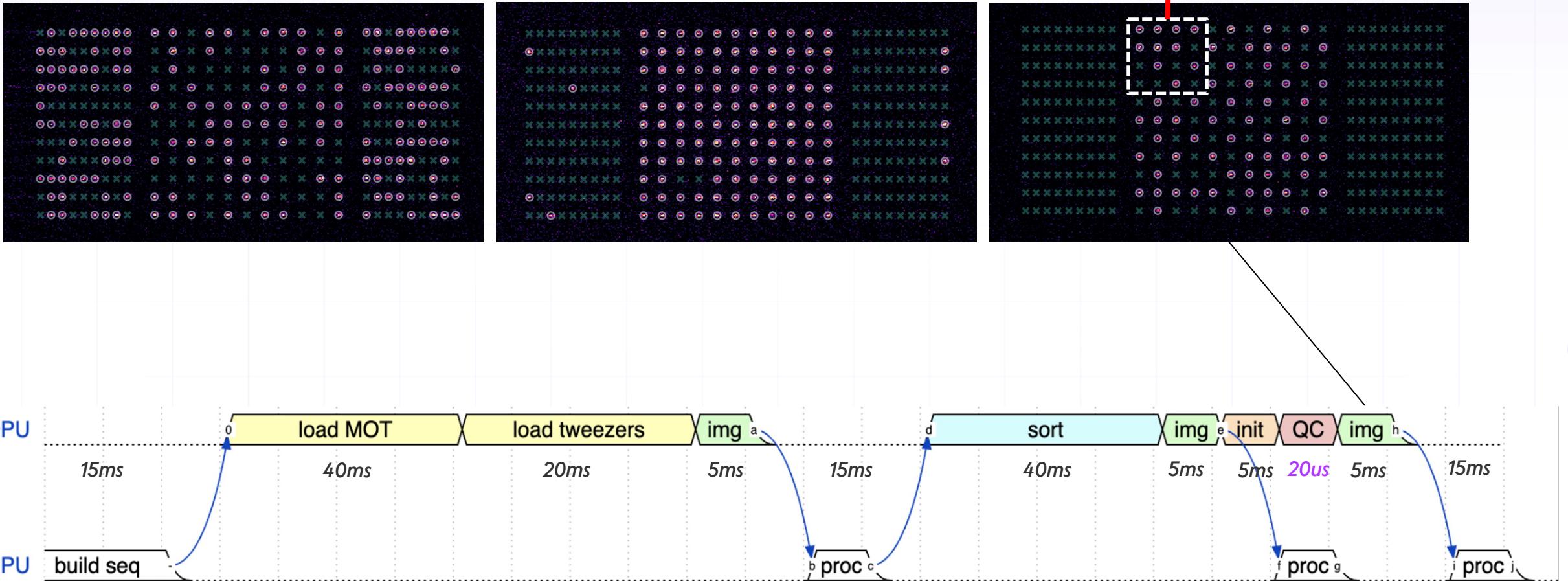


Coherent evolution

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



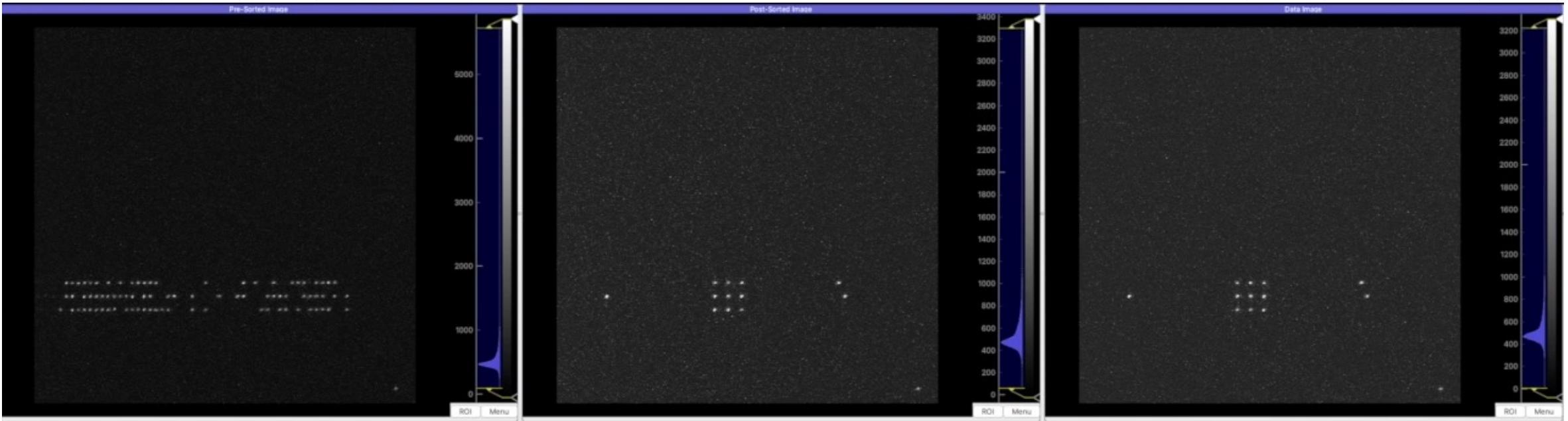
# QPU cycle



# Sneak peek into the running engine

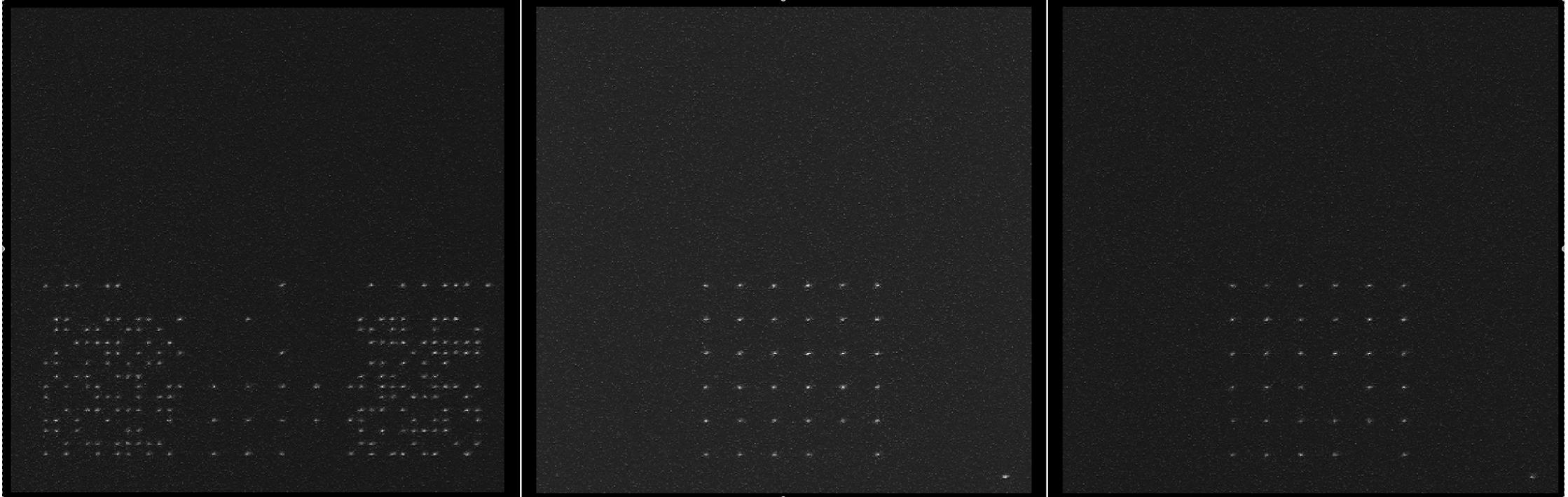
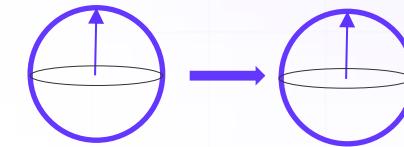


# Sneak peek into the running engine



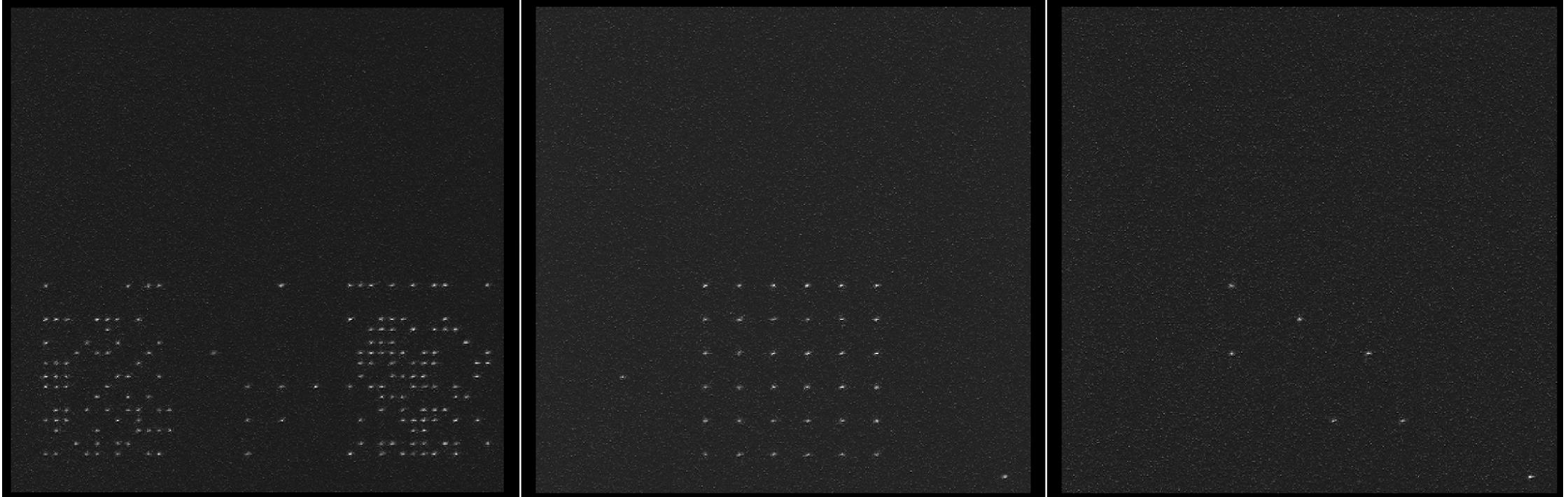
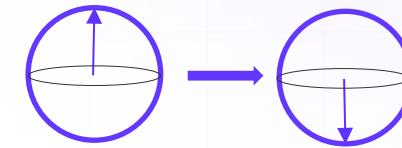
# What qubit control really looks like:

*2π pulse*



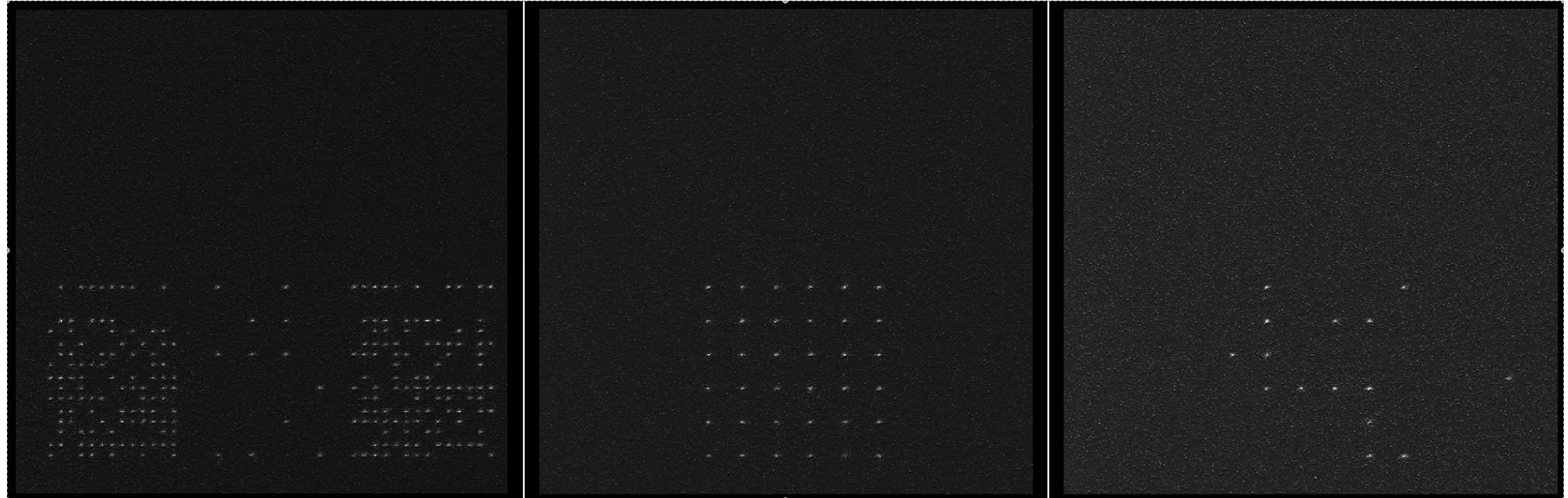
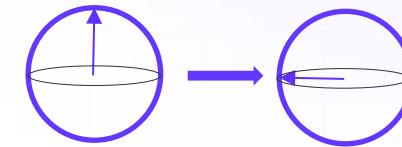
# What qubit control really looks like:

*$\pi$  pulse*

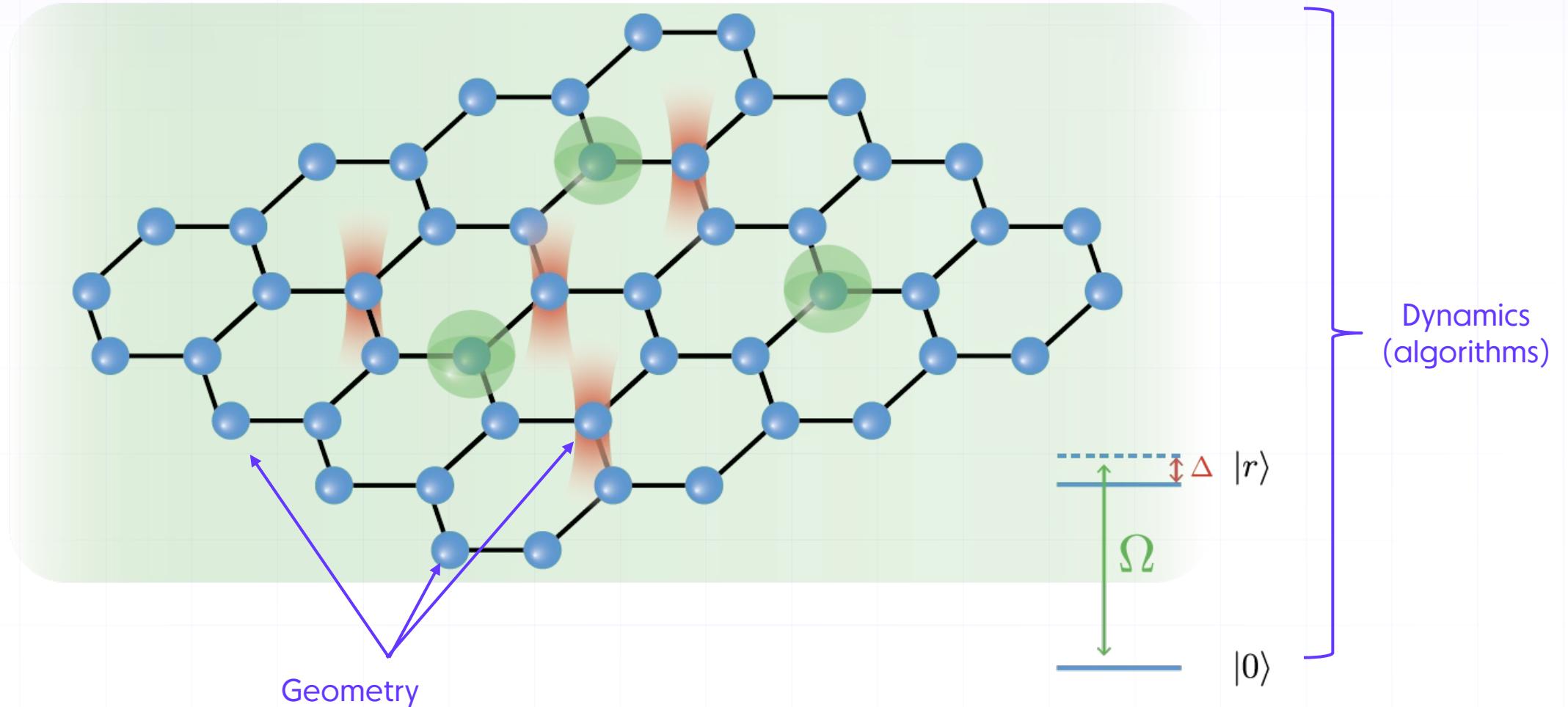


# What qubit control really looks like:

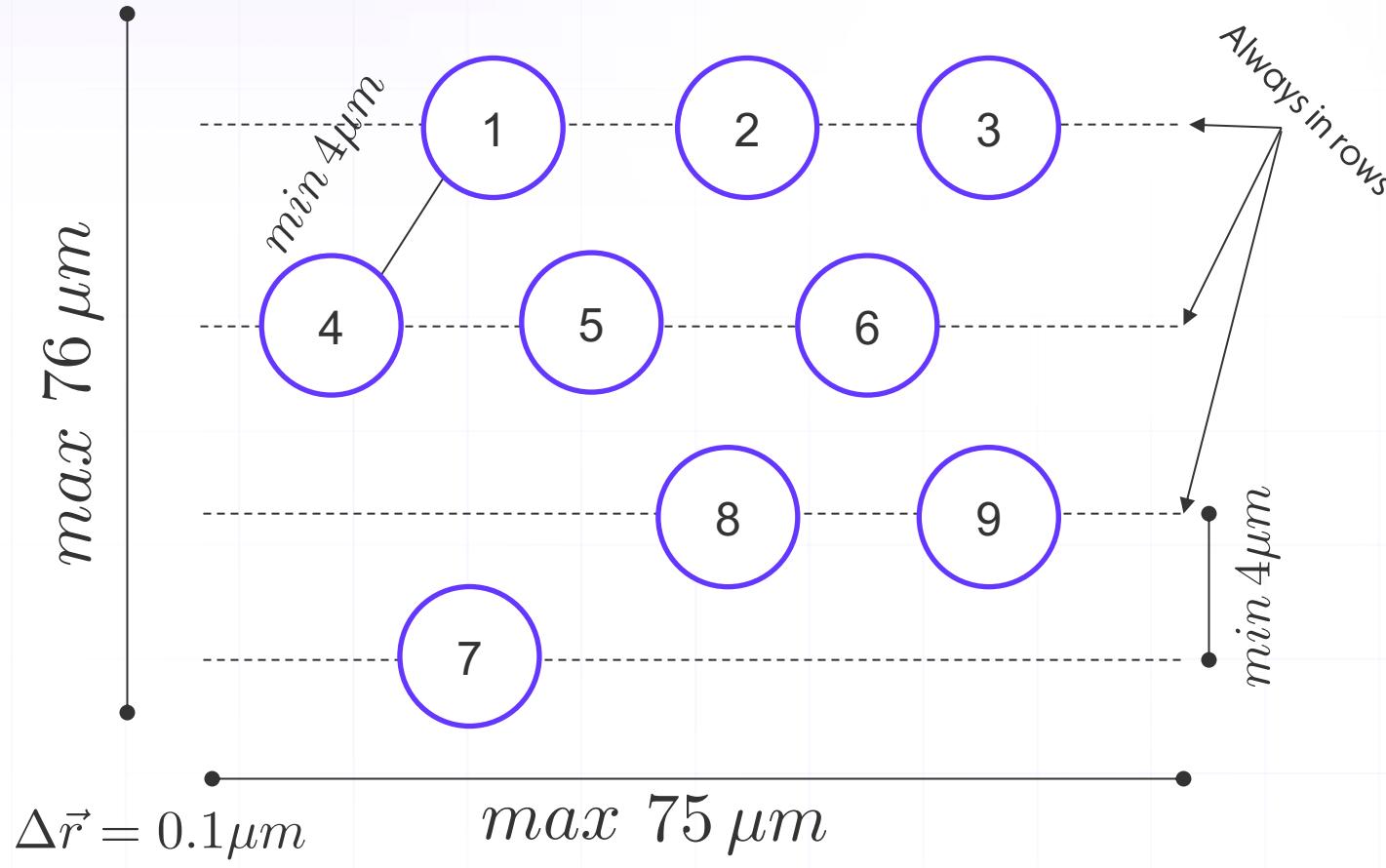
$\pi/2$  pulse



# A neutral-atom quantum processor



# Hardware constraints: Geometry



## Activity 1:

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

## Activity 2:

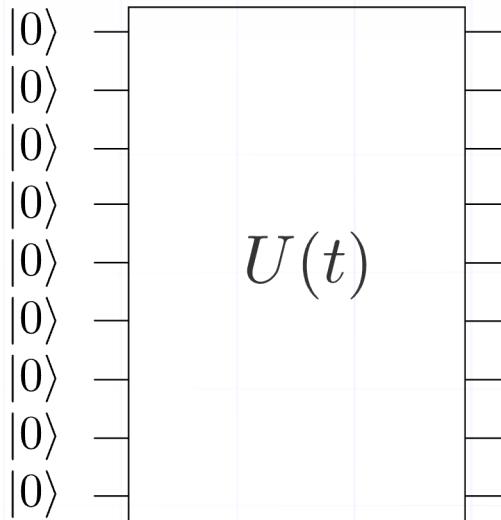
defining qubit positions on Bloqade

More details @

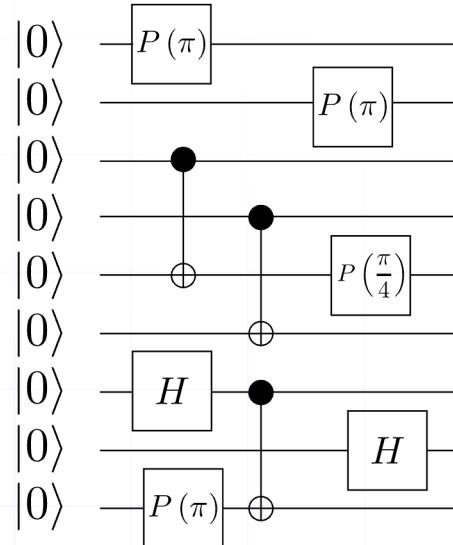
<https://queracomputing.github.io/Bloqade.jl/dev/capabilities/>

# Information processing: Analog computing

Analog operation



Digital operation



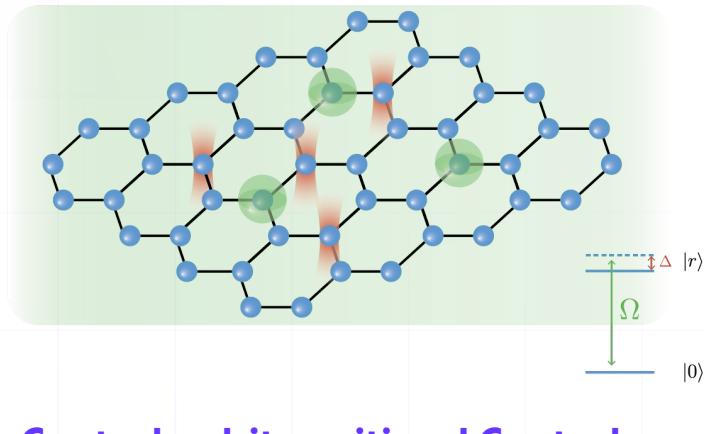
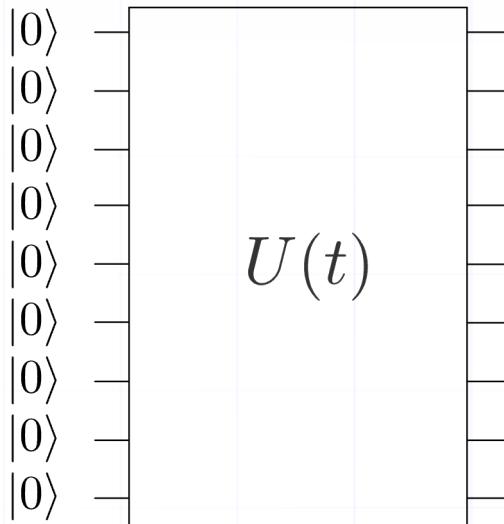
Designed for the early stage of maturity of the quantum computing resources of today...

- ✓ 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!**

⇒ Many possibilities!

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

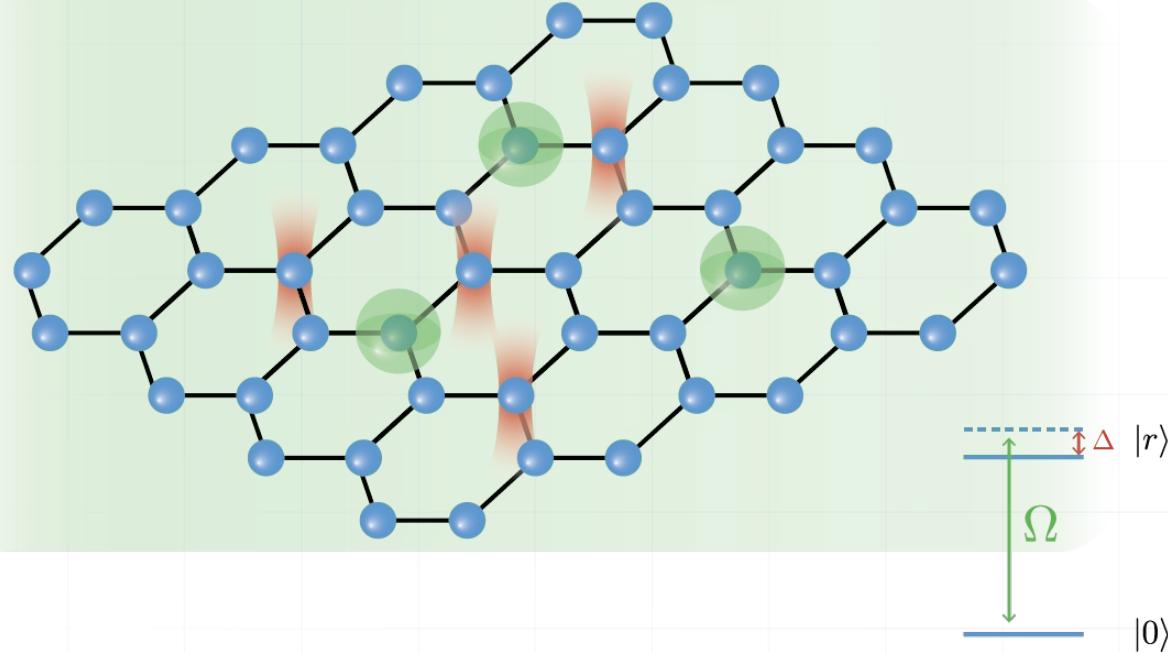
More on analog processors:  
[Nature volume 607](#), p. 667–676 (2022)

# Algorithm = time evolution

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

# Analog quantum dynamics control

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

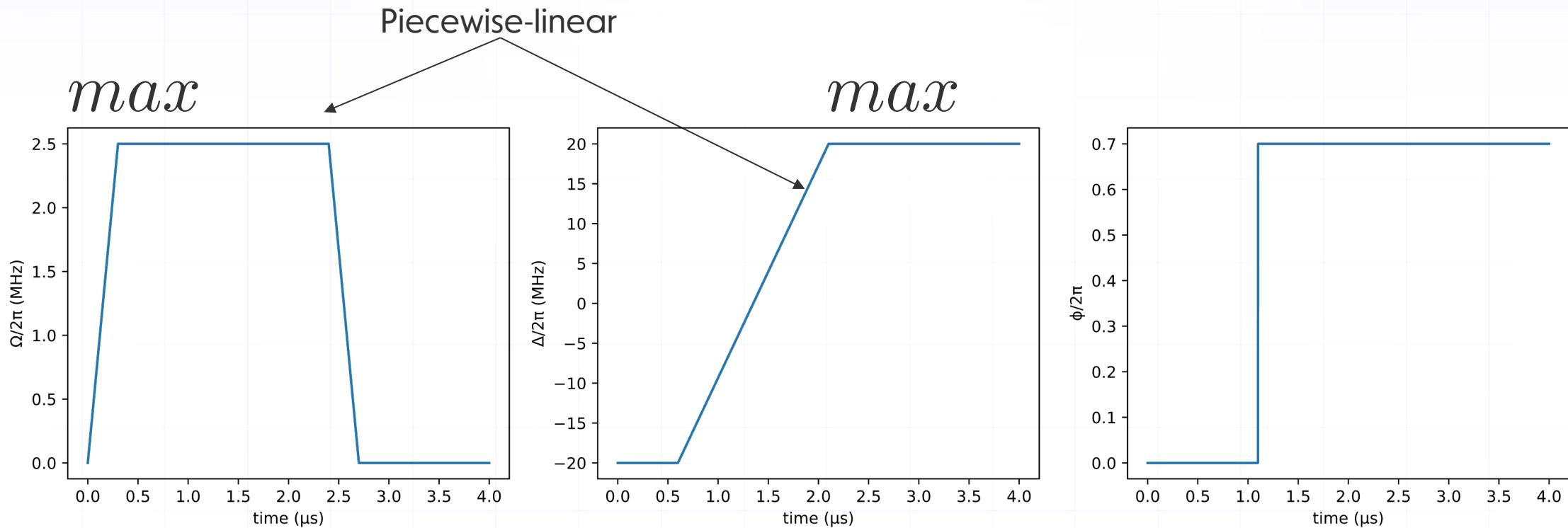


$$n_i = 1 * |r_i\rangle\langle r_i| + 0 * |g_i\rangle\langle g_i|$$

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

# Hardware constraints: dynamics

Activity: Encoding waveforms on Bloqade

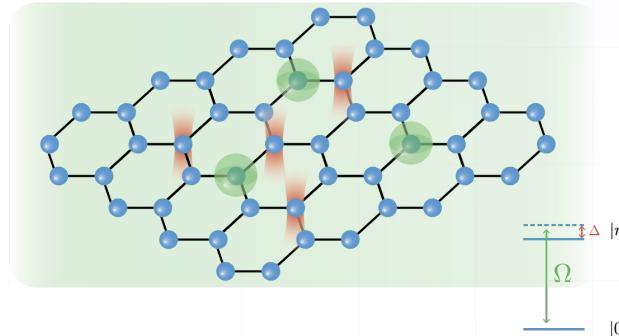
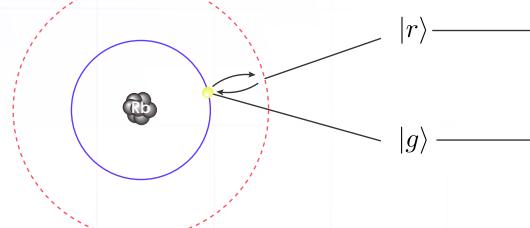


$$t_{max} = 4 \mu s$$

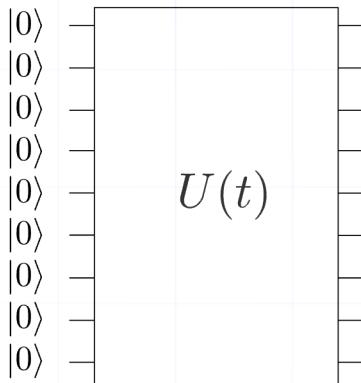
Piecewise-constant

# Summary

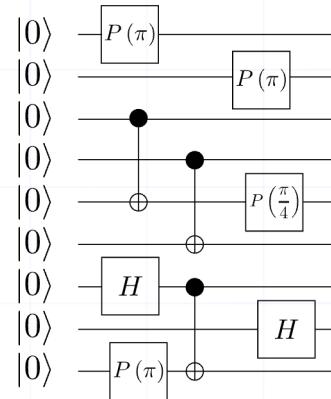
## Architecture



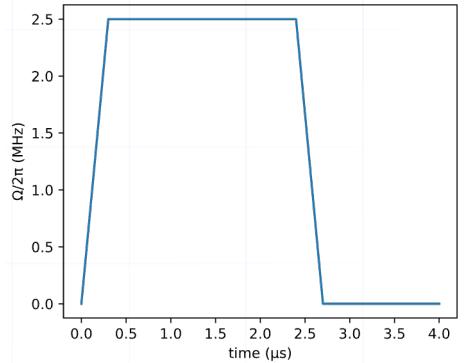
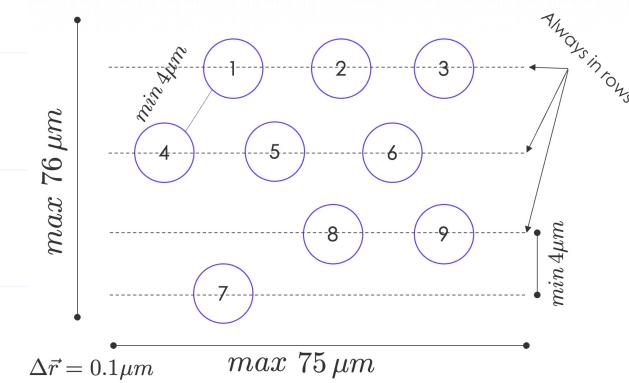
## Analog operation



## Digital operation



## Hardware constraints



# Learning objectives

Now you are able to:

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