SynQS

Overview

Trento Summer school
Fred Jendrzejewski

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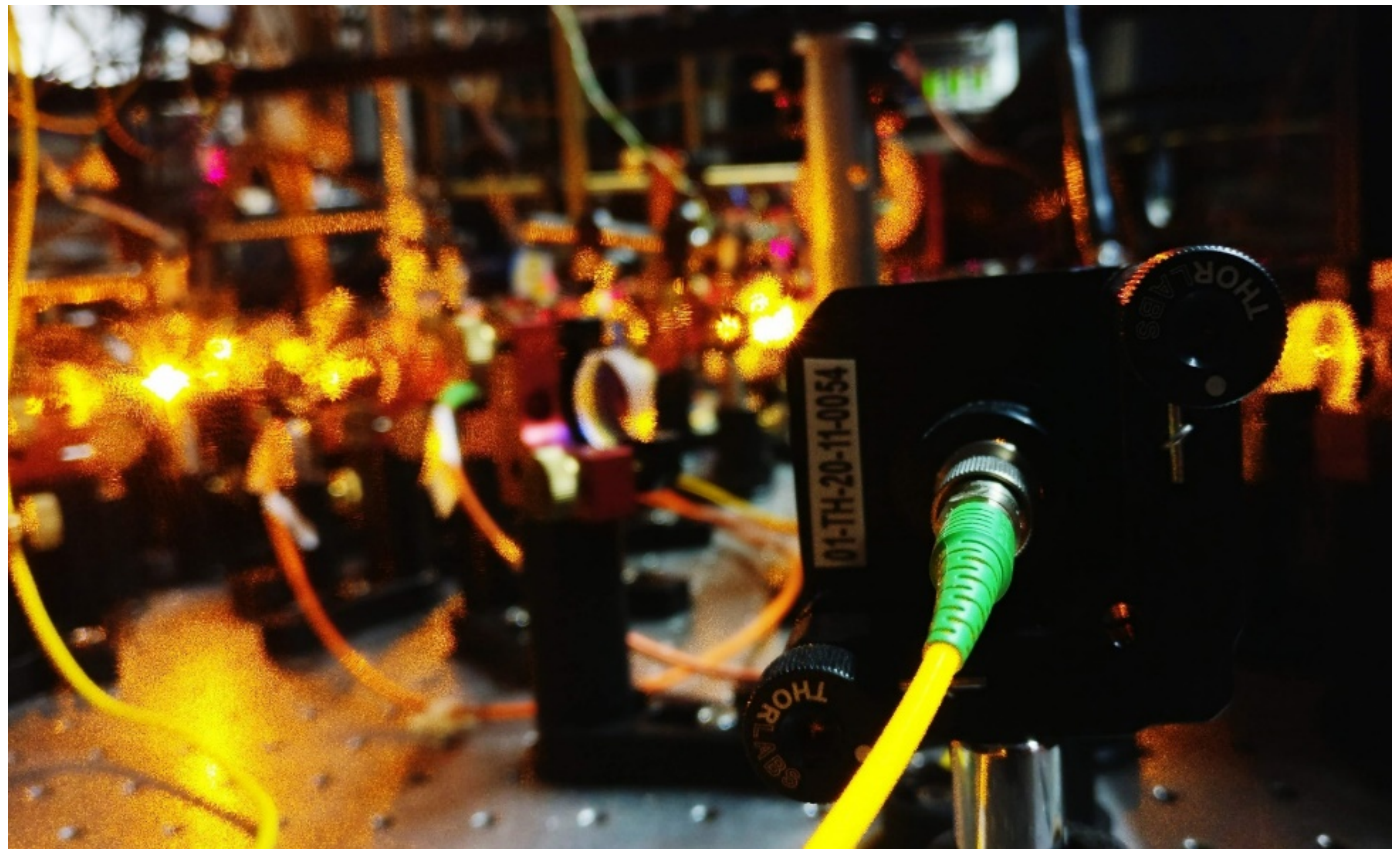
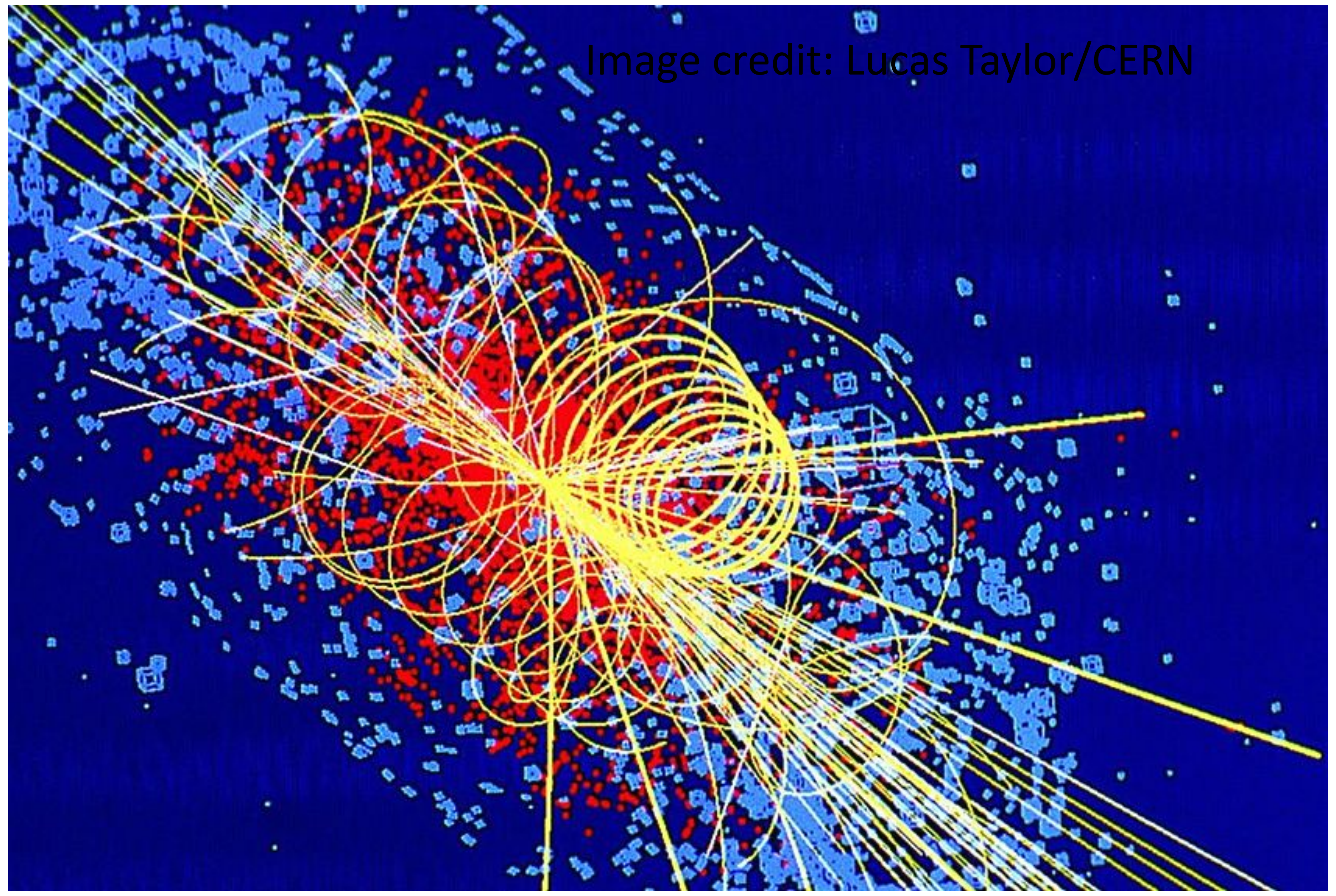
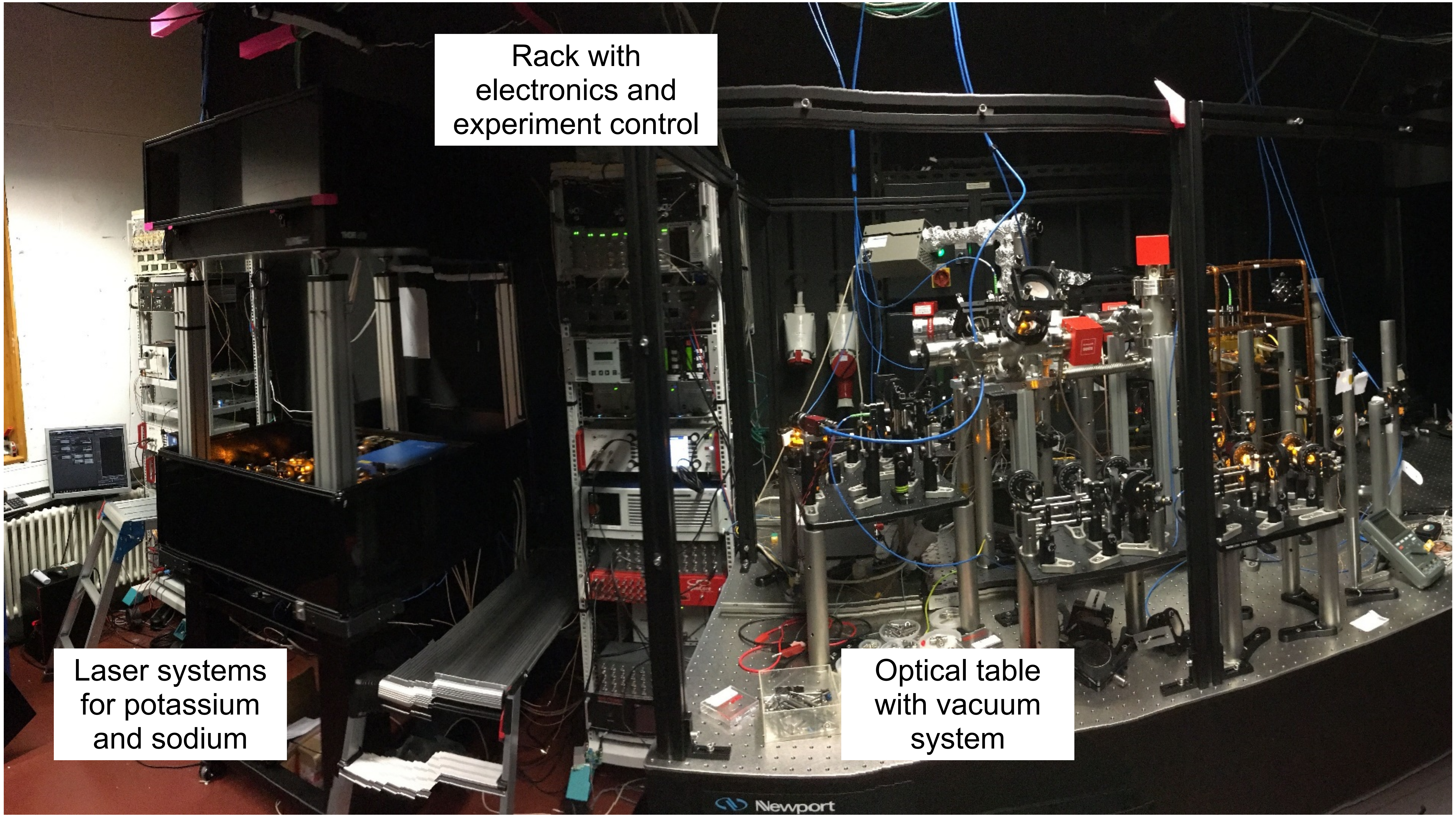
Could we use cold atoms to study high-energy physics?

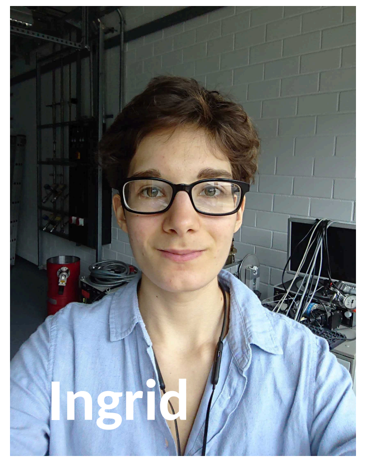





Rack with electronics and experiment control
Laser systems for potassium and sodium
Optical table with vacuum system
Newport


Lilo

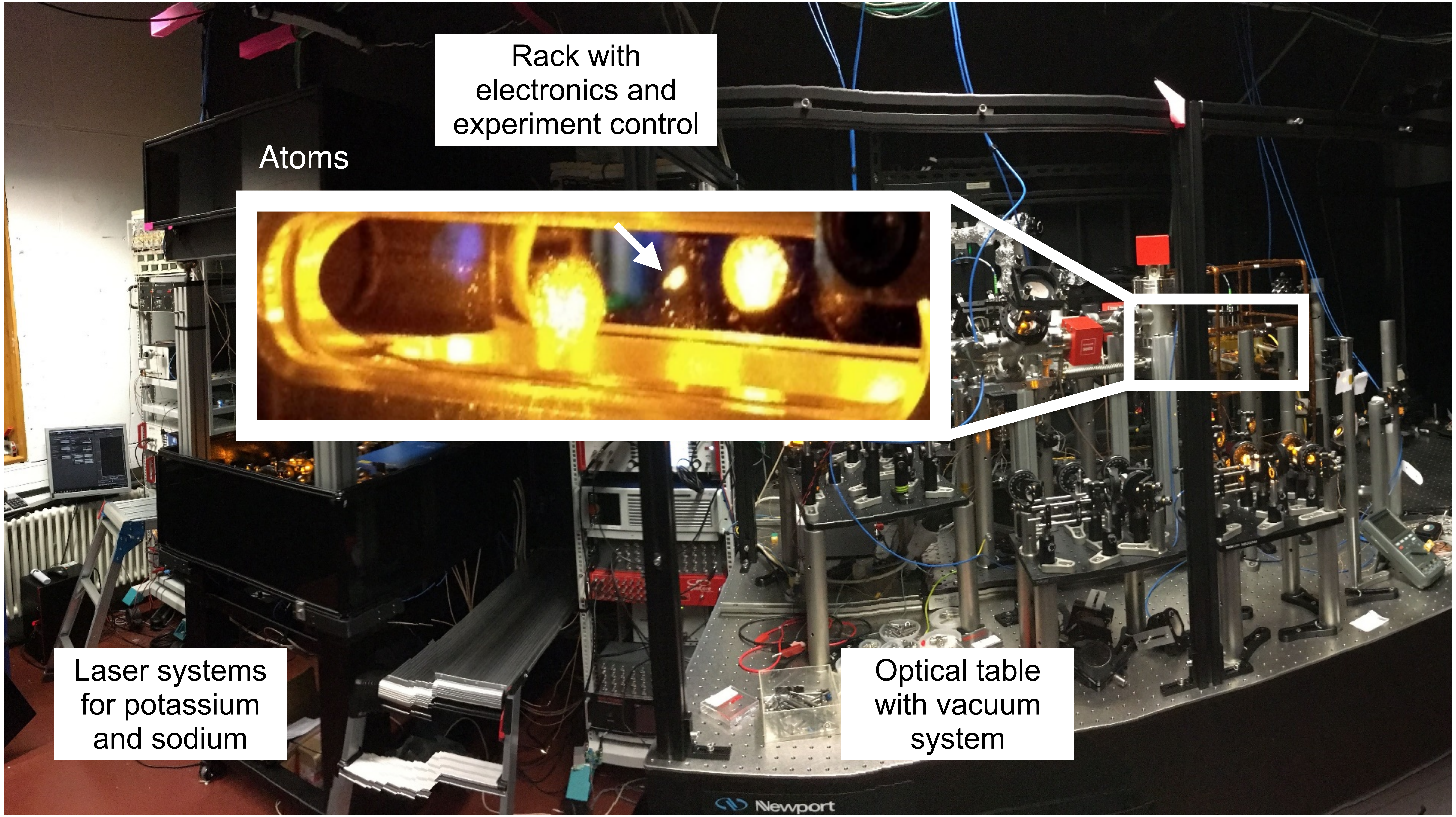
Jan

Hannes

Ingrid

Apoorva

Andy

Rohit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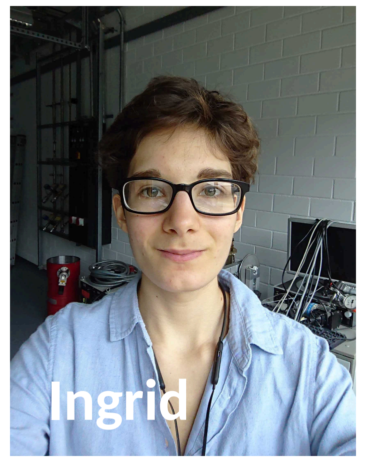
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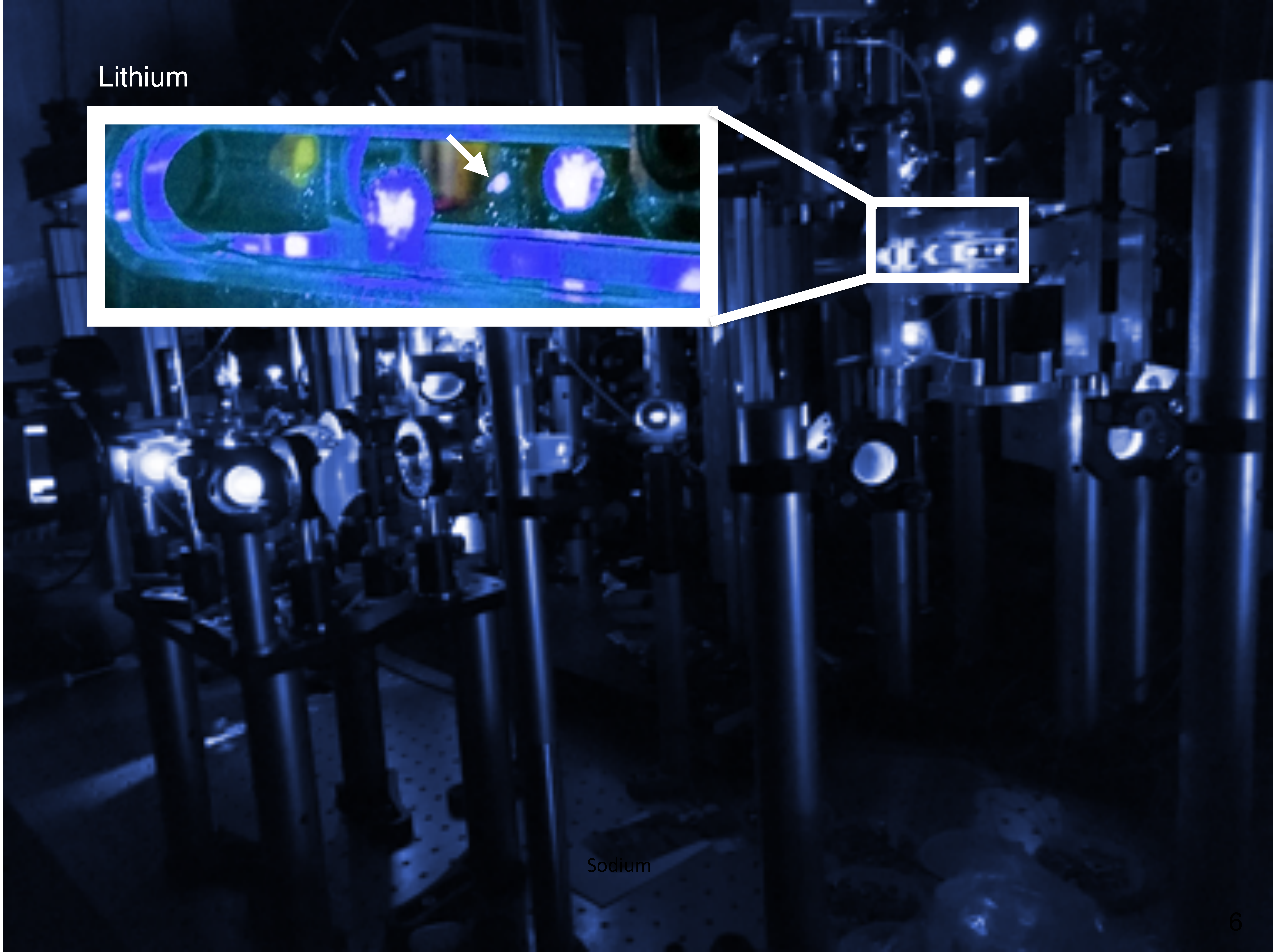
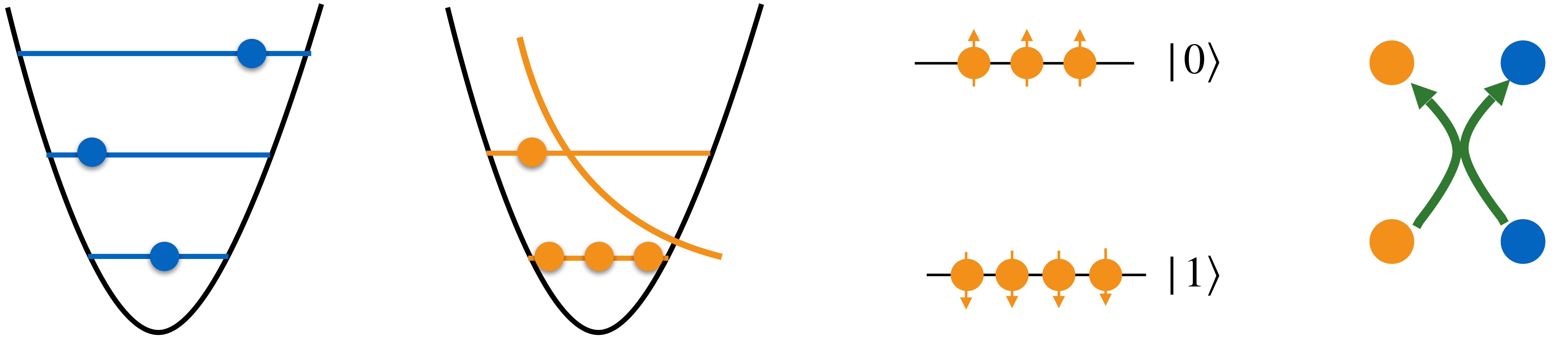
Sodium


Lithium
Sodium



Confinement | Temperature | Spin | Interactions

$$\hat{H} = \int d^3\mathbf{x} \sum_{\alpha} \hat{\psi}^{\dagger}_{s,\alpha}(\mathbf{x}) \left[\frac{-\nabla^2_{\mathbf{x}}}{2m_s} + V_s(\mathbf{x}) + E_{s,\alpha}(B) \right] \hat{\psi}_{s,\alpha}(\mathbf{x}) + \frac{1}{2} \int d^3\mathbf{x} \sum_{\alpha,\beta} g^{s}_{\alpha\beta} \hat{\psi}^{\dagger}_{s,\alpha}(\mathbf{x}) \hat{\psi}^{\dagger}_{s,\beta}(\mathbf{x}) \hat{\psi}_{s,\beta}(\mathbf{x}) \hat{\psi}_{s,\alpha}(\mathbf{x})$$

$$+ \int d^3\mathbf{x} \sum_{\alpha,\beta} g^{Mix}_{\alpha\beta} \hat{\psi}^{\dagger}_{N,\alpha}(\mathbf{x}) \hat{\psi}^{\dagger}_{L,\beta}(\mathbf{x}) \hat{\psi}_{L,\beta}(\mathbf{x}) \hat{\psi}_{N,\alpha}(\mathbf{x})$$

All microscopic parameters known

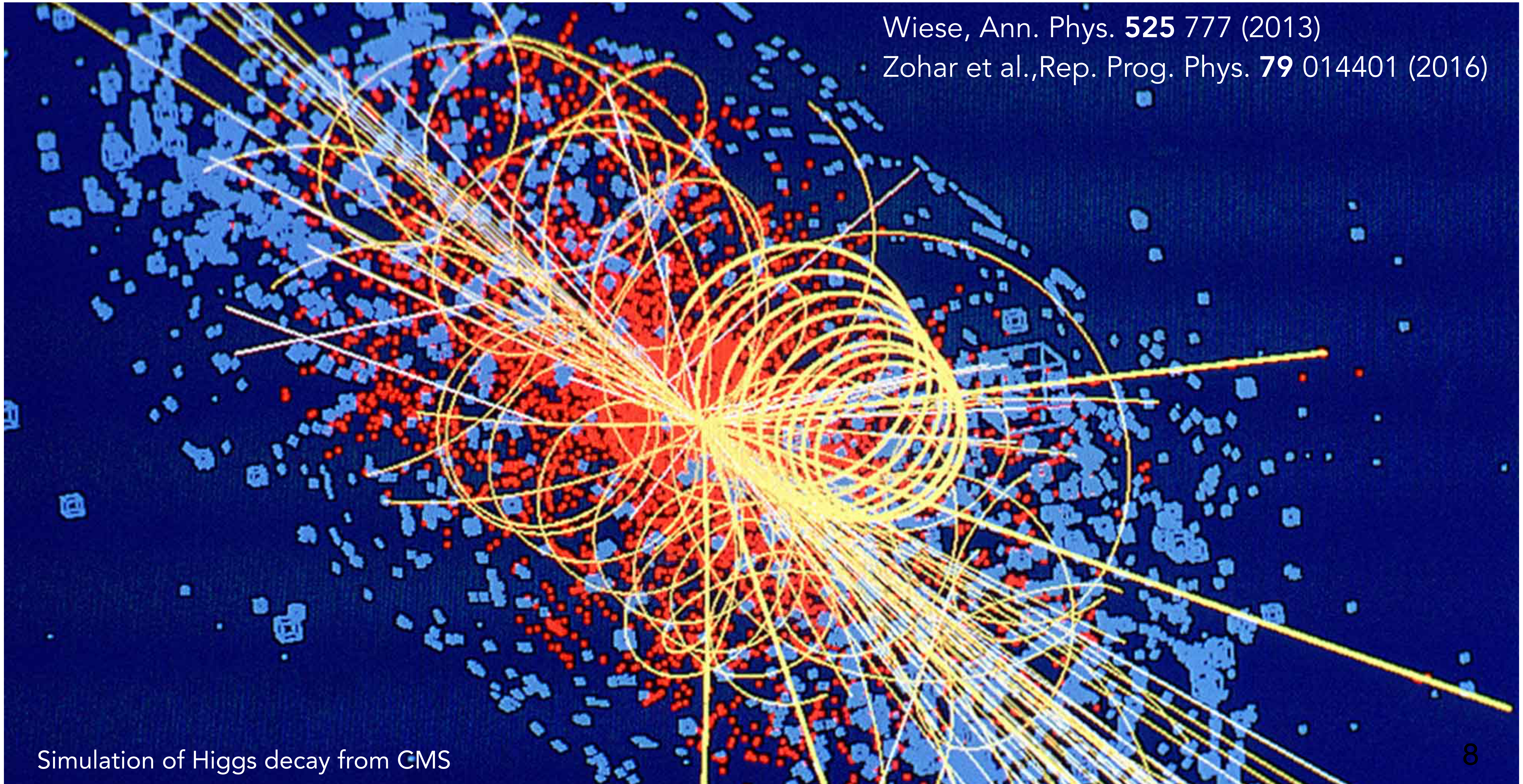
I. Bloch et al., Rev. Mod. Phys. **80**, 885 (2008).

$$\mathscr{L}_{QED} = \bar{\psi}\left(i\gamma^{\mu}D_{\mu} - m\right)\psi - \frac{1}{4}F^{\mu\nu}F_{\mu\nu}$$

$$\mathscr{L}_{QCD} = \sum_{fi} \bar{\psi}^{fi}\left(i\gamma^{\mu}D_{\mu ij} - m_f\right)\psi^{fi} - \frac{1}{2g^2}Tr\left(G^{\mu\nu}G_{\mu\nu}\right)$$

Particle

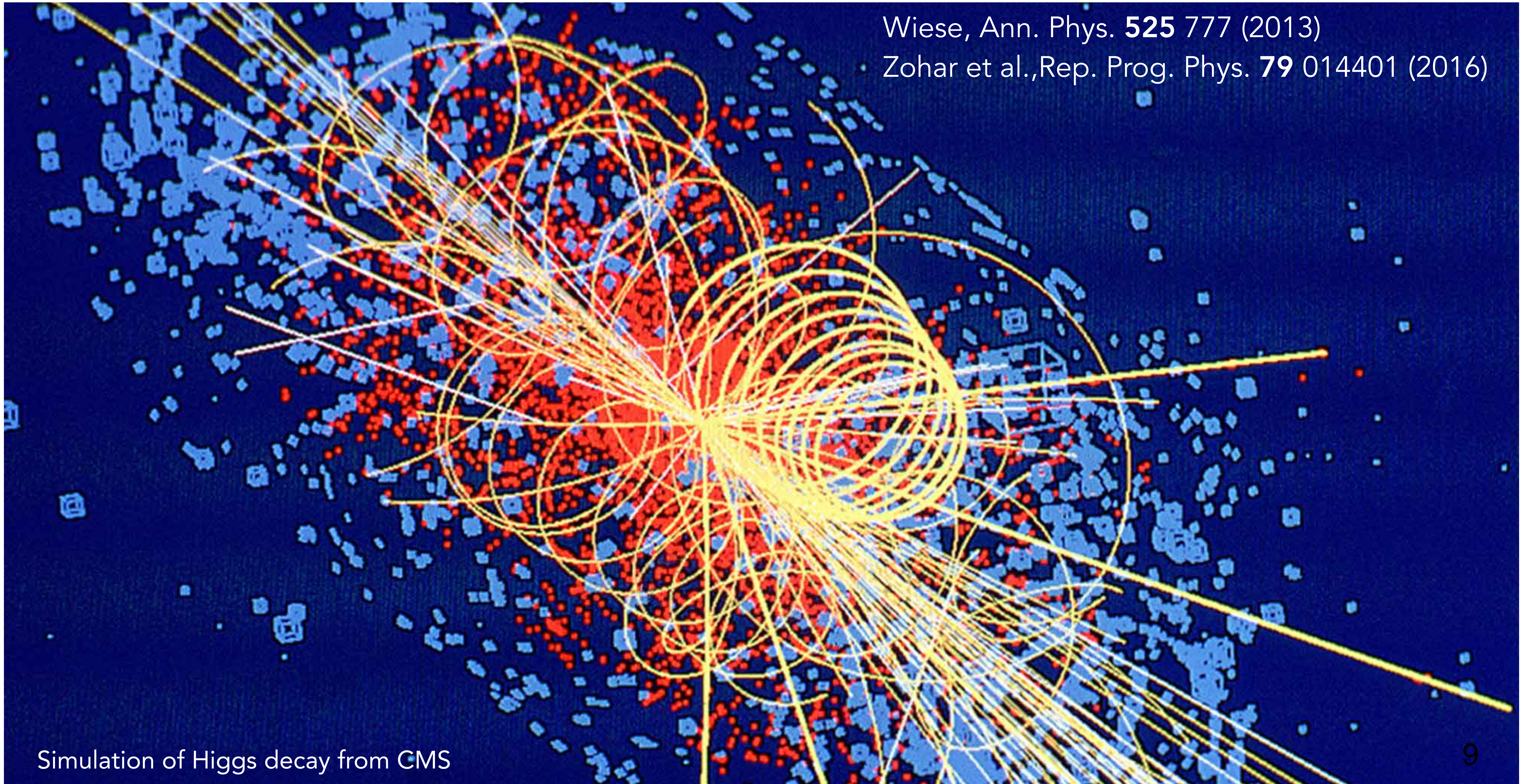
Gauge field



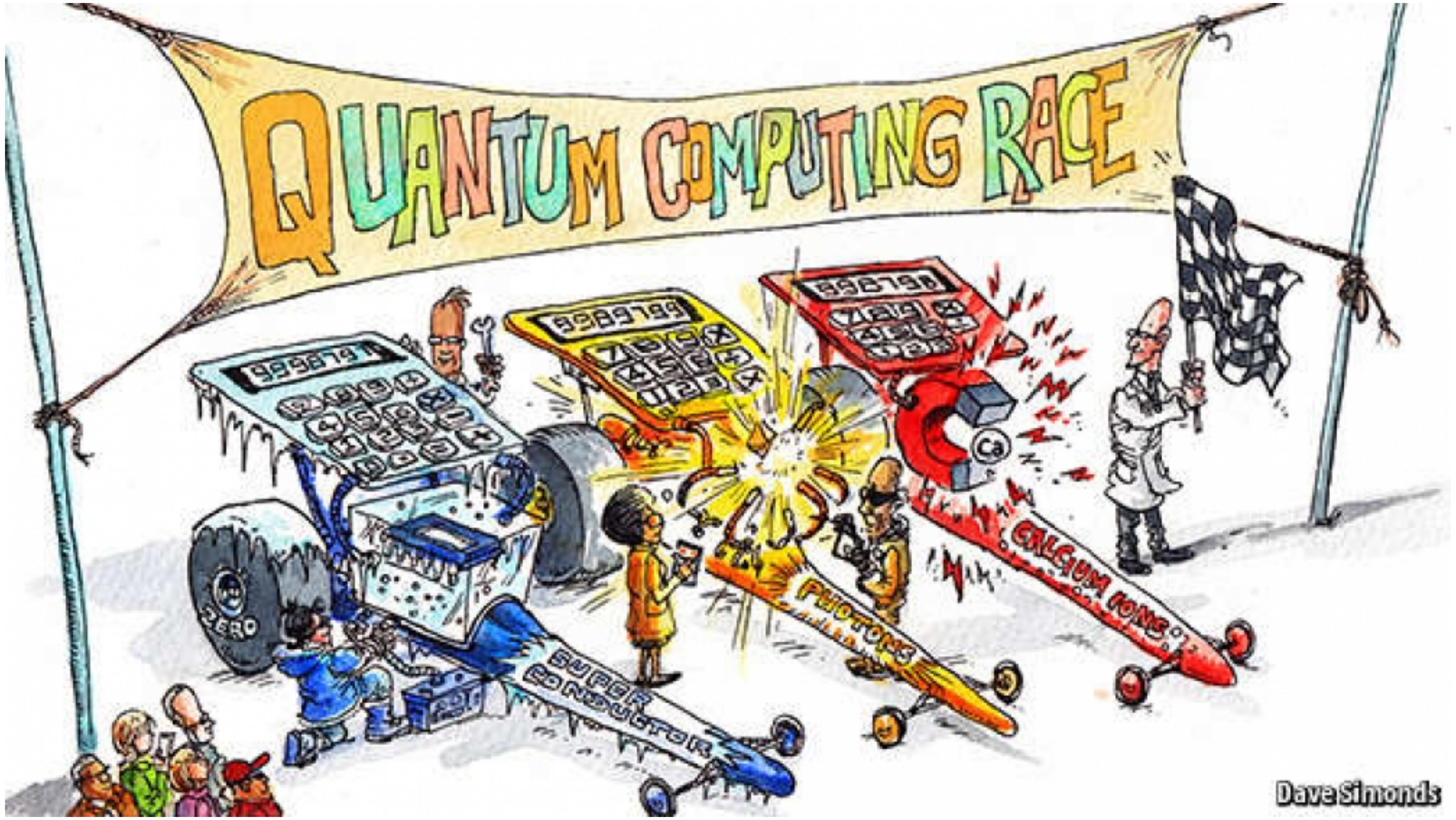
$$\mathscr{L}_{QED} = \bar{\psi}\left(i\gamma^{\mu} D_{\mu} - m\right)\psi - \frac{1}{4}F^{\mu\nu}F_{\mu\nu}$$

$$\mathscr{L}_{QCD} = \sum_{fi} \bar{\psi}^{fi}\left(i\gamma^{\mu} D_{\mu ij} - m_f\right)\psi^{fi} - \frac{1}{2g^2}Tr\left(G^{\mu\nu}G_{\mu\nu}\right)$$

Particle Gauge coupling Gauge field



Various candidate platforms for quantum computer exist



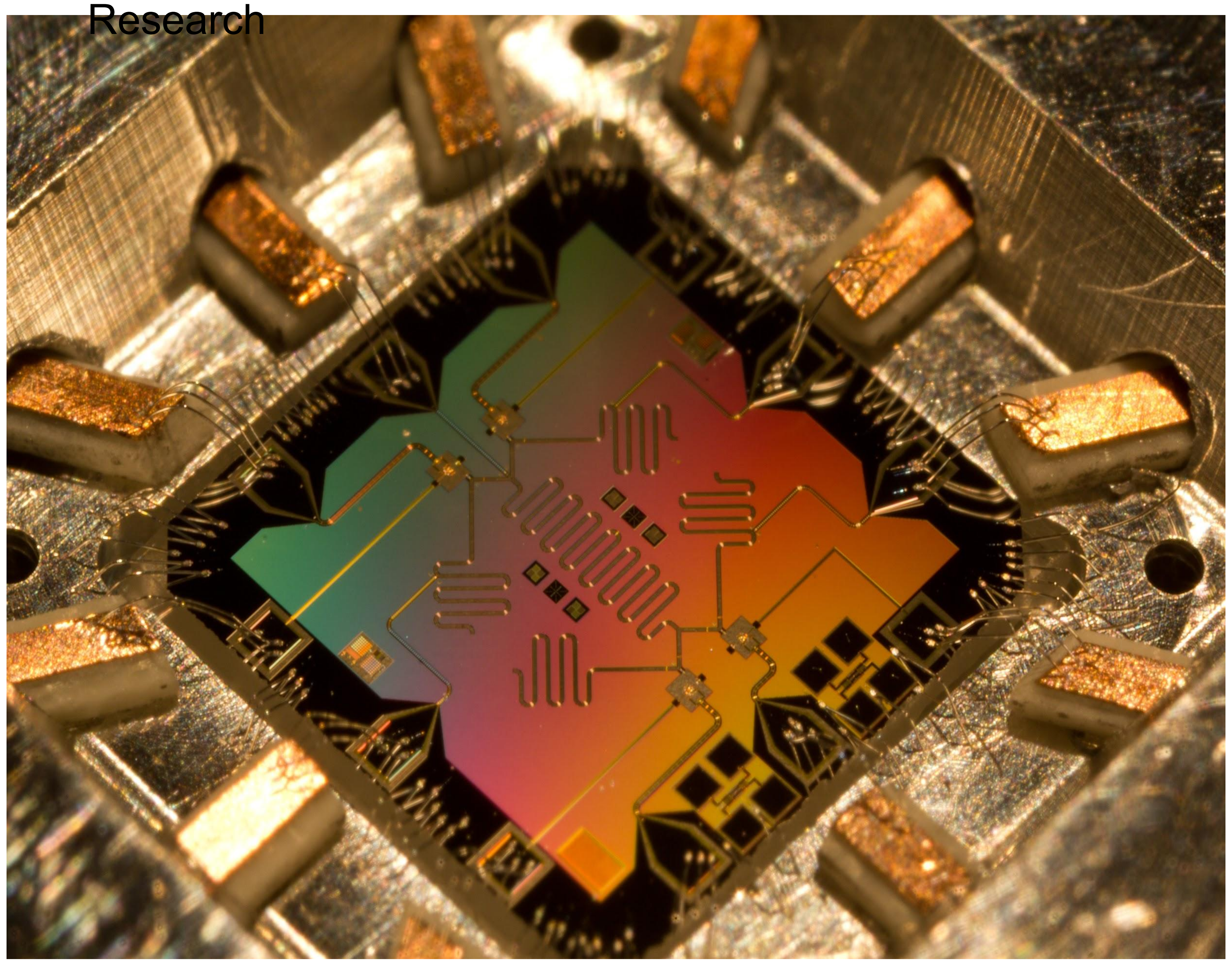
The economist

At least in near future:

Not „winnter takes all“, but complementarity for different tasks

Superconducting Qubits

Martinis lab, UCSB and Google Research



- Superconducting electrical components
- Excitations of superconductor forms qubit

Strengths

- Integrated in electrical circuit
- Control with GHz frequencies

Open questions

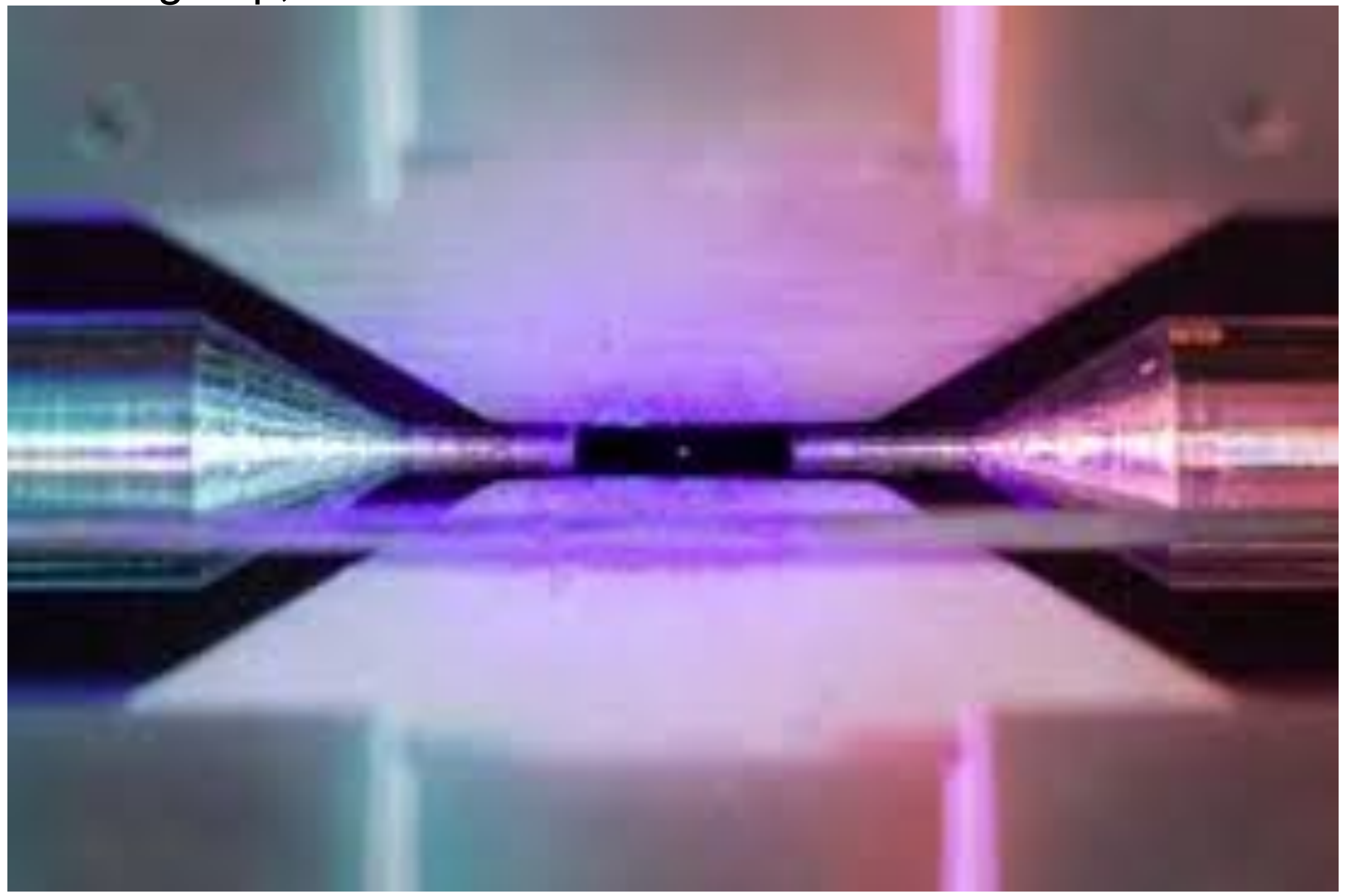
- Non - local coupling of qubits
- Quantum supremacy in D-Wave systems

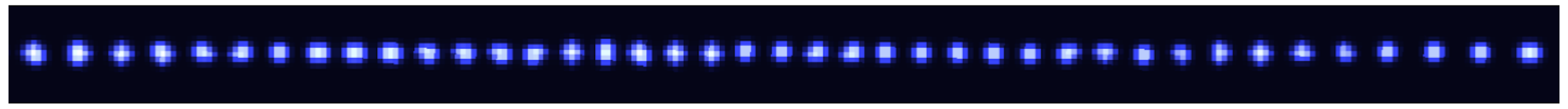
Important commercial players

- IBM
- Google
- Rigetti

Trapped Ions

Lucas group, Oxford





Monroe group, JQI Maryland

- Charged particles
- Electrostatic traps
- Laser and microwave operations

Strengths

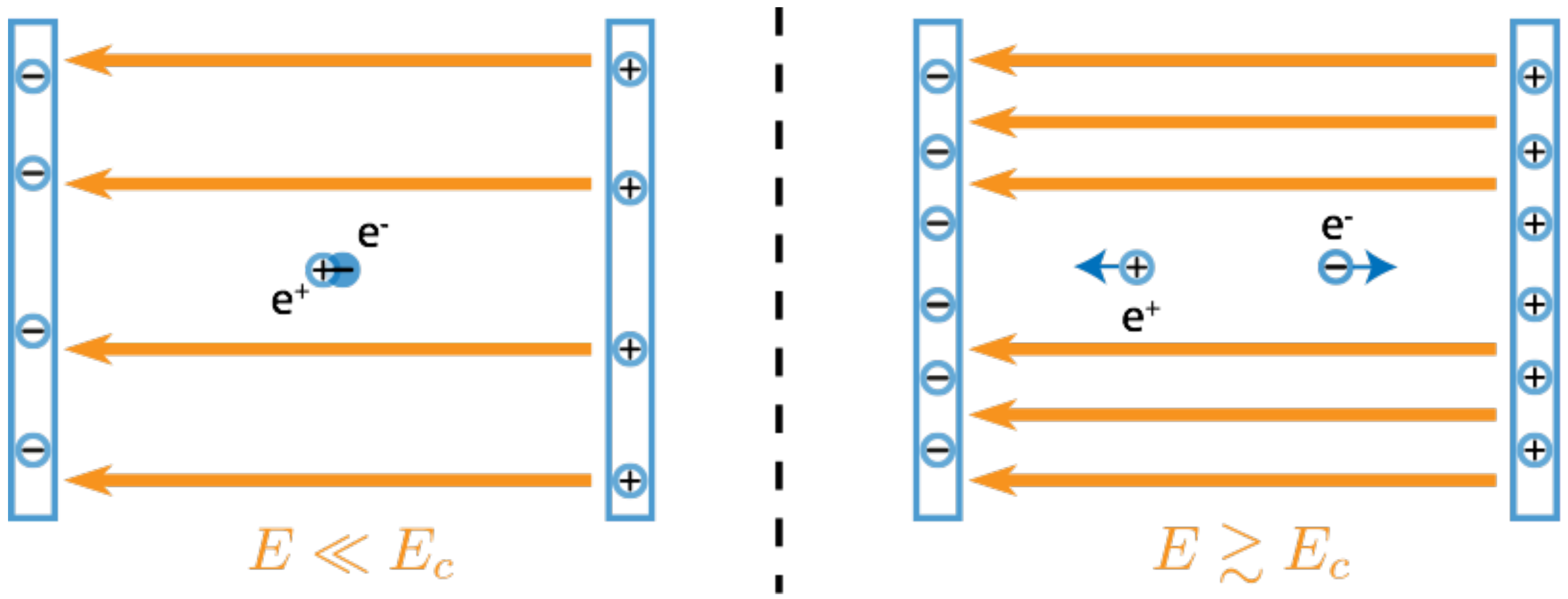
- Highest gate fidelities
- Fast experimental timescales

Open questions

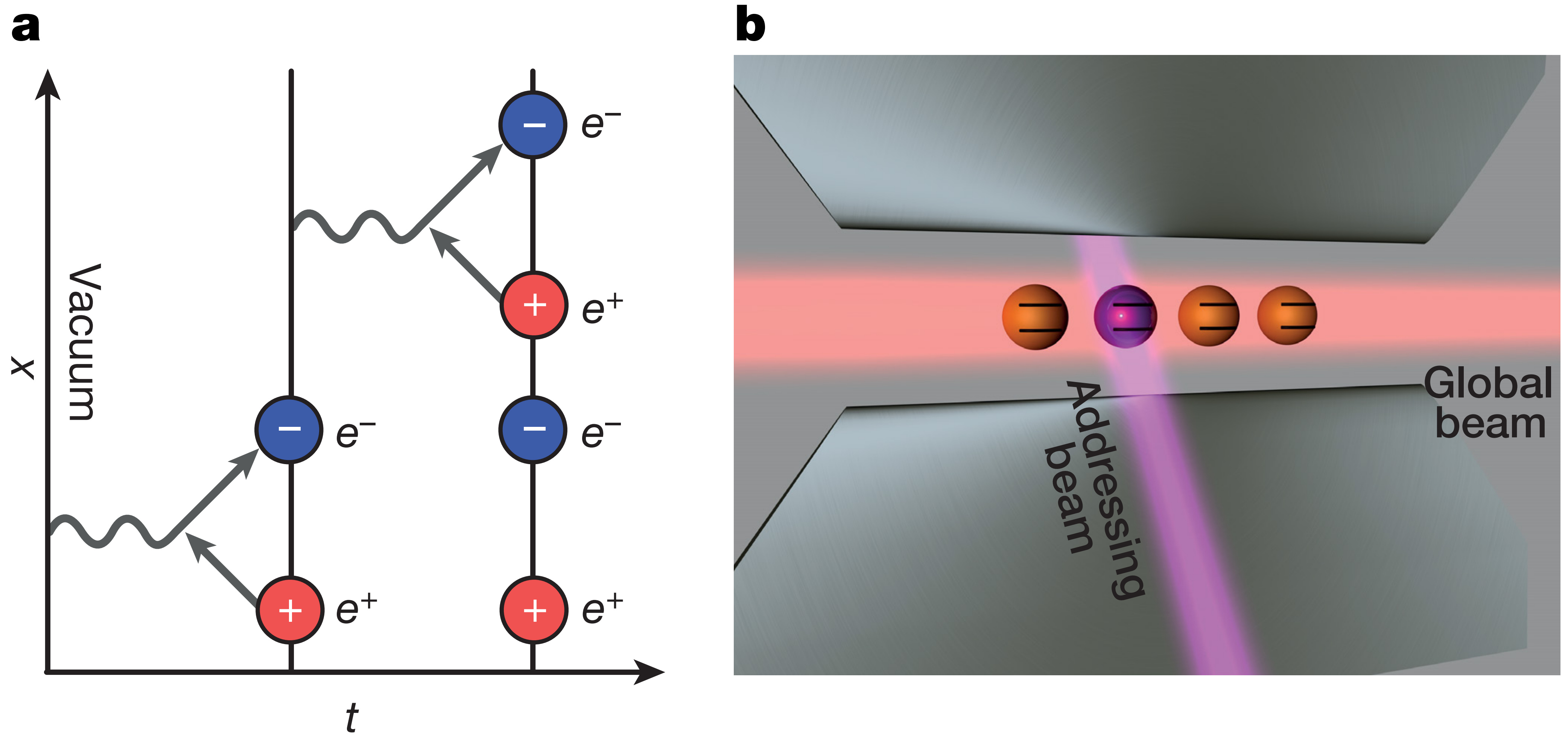
- Maximum size 50 qubits so far
- Challenging scalability

Important commercial players

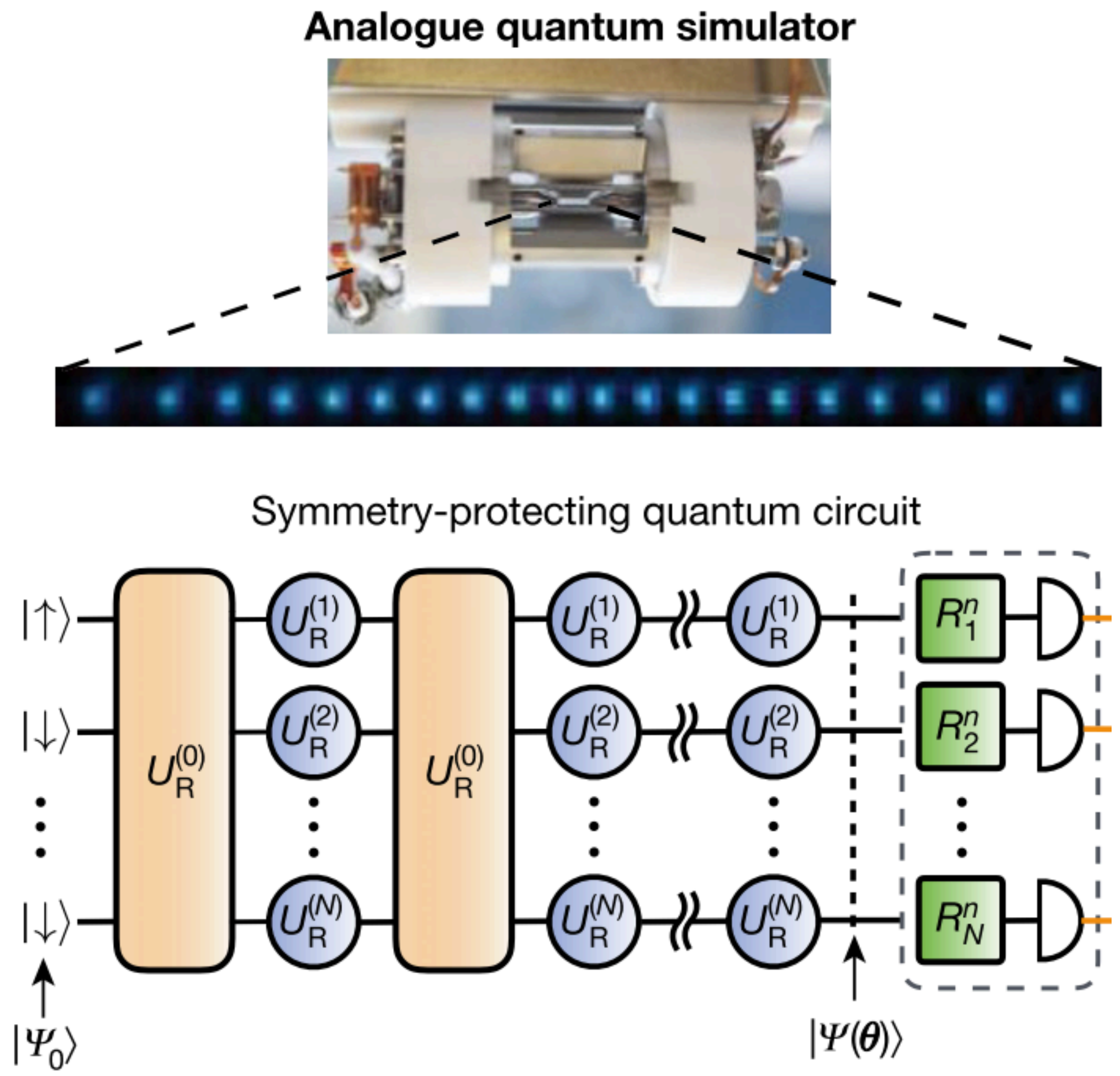
- IonQ (JQI)
- AQT (Innsbruck)
- Honeywell (JILA)



First digital
implementation with ions



E. Martinez et al., Nature **534** 516 (2016).

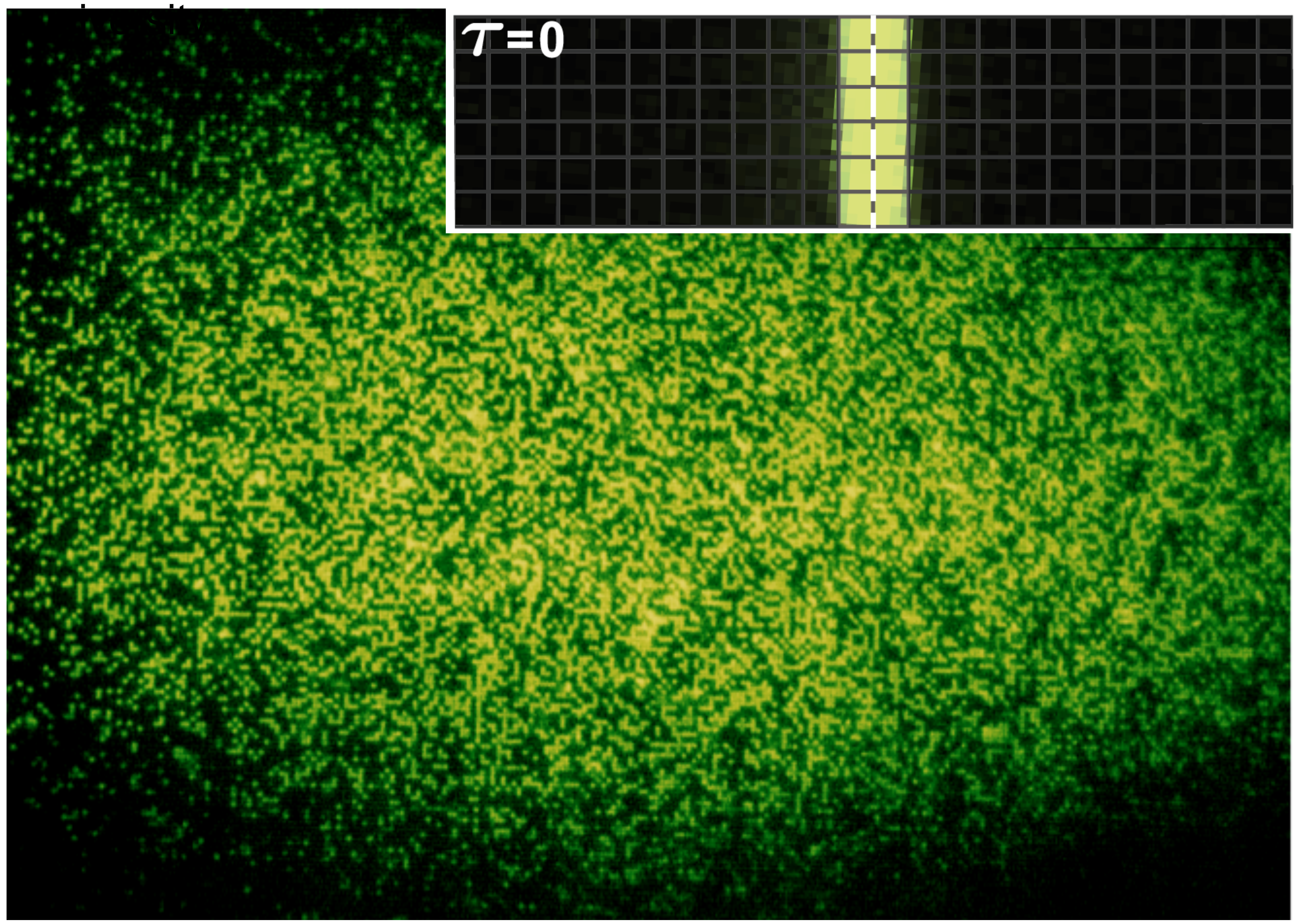


C. Kokail et al., Nature **569**, 355 (2019).

See Martin Ringbauer next week

Neutral atoms

Greiner group, Harvard



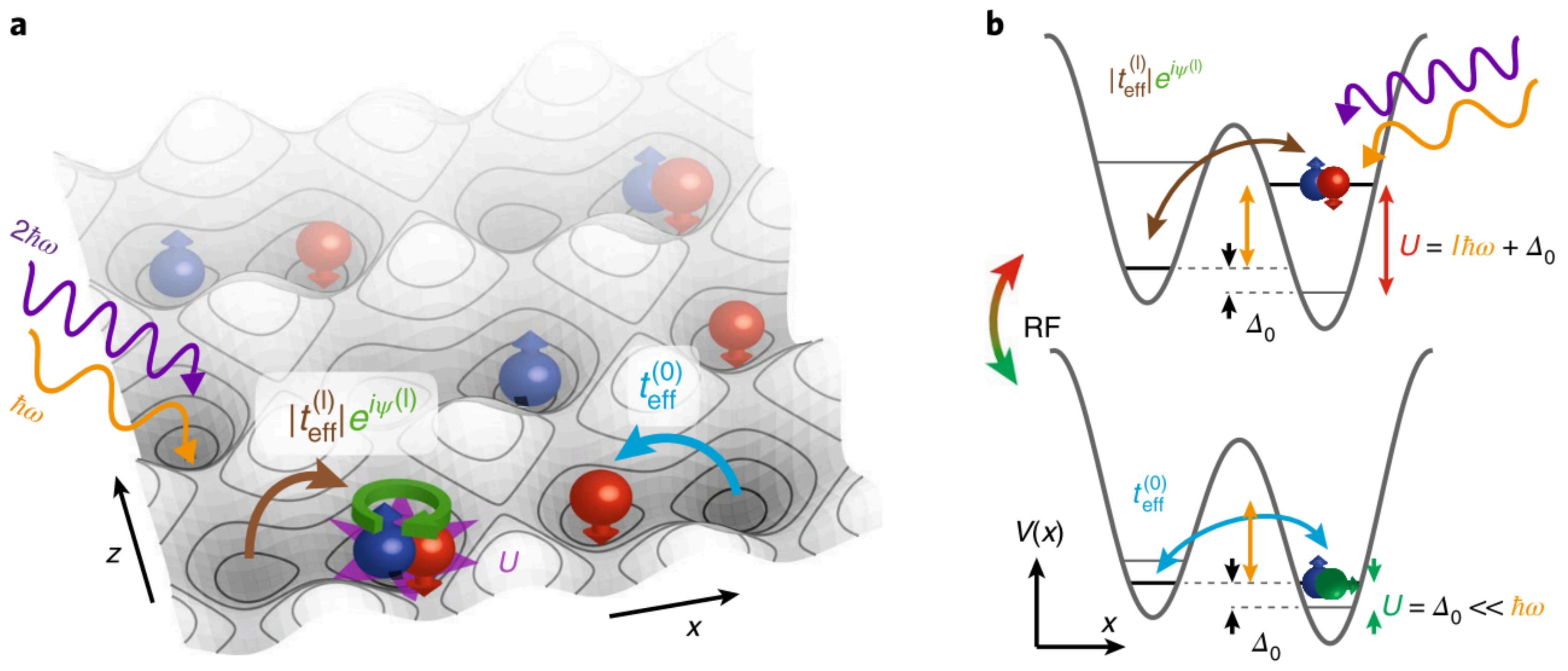
- Neutral laser-cooled particles
- Optical potentials
- Single-particle readout and control

Strengths

- Many hundreds of particles
- Very scalable solution

Lukin group, Harvard university

F. Görg et al.,
Nat. Phys. **15**, 1161 (2019).



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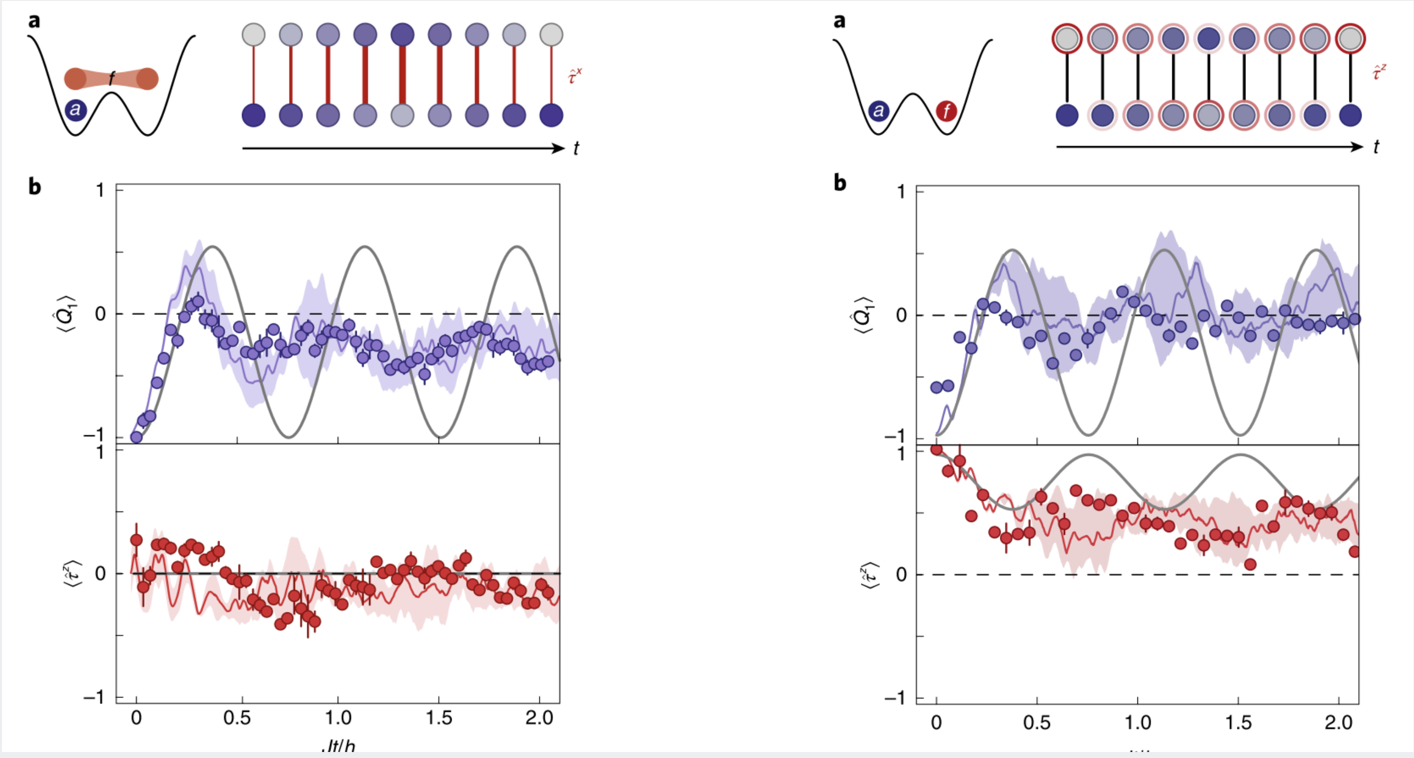
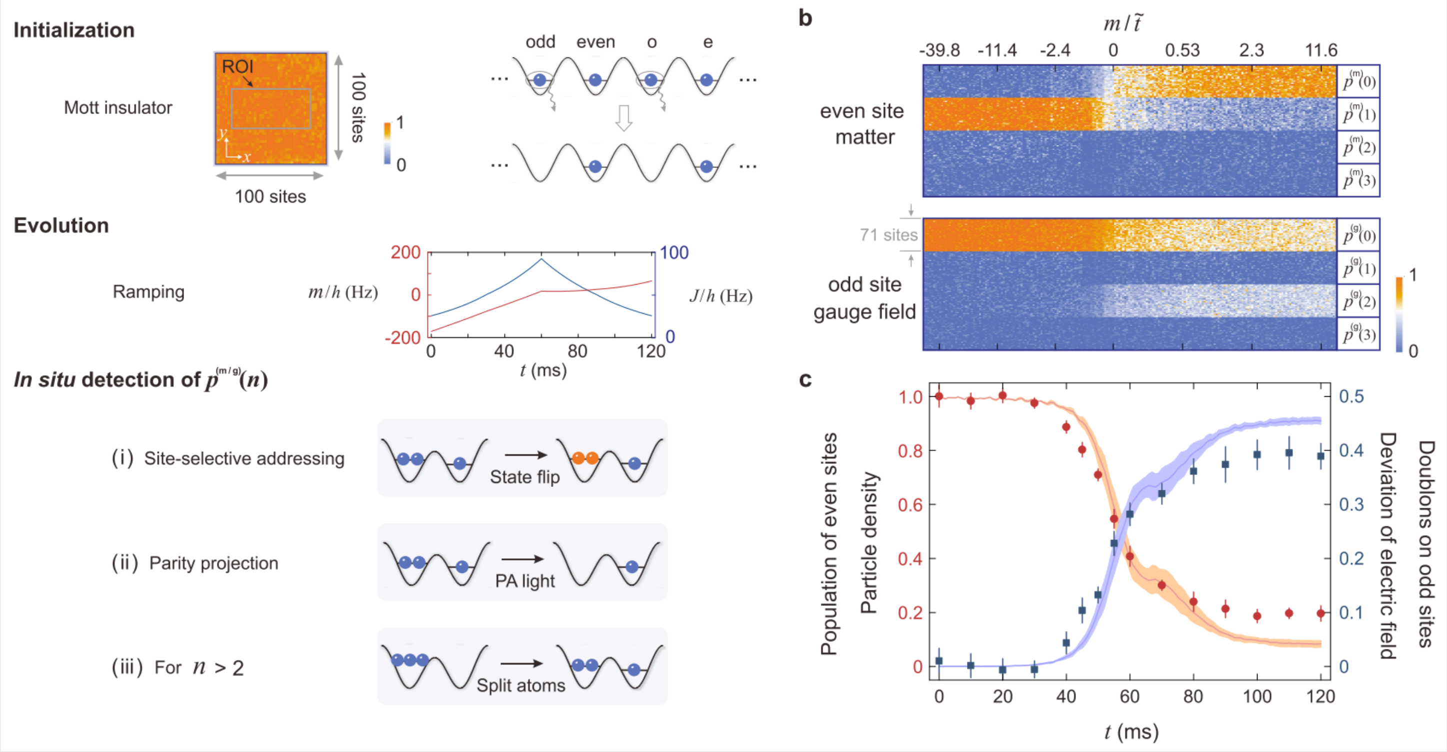
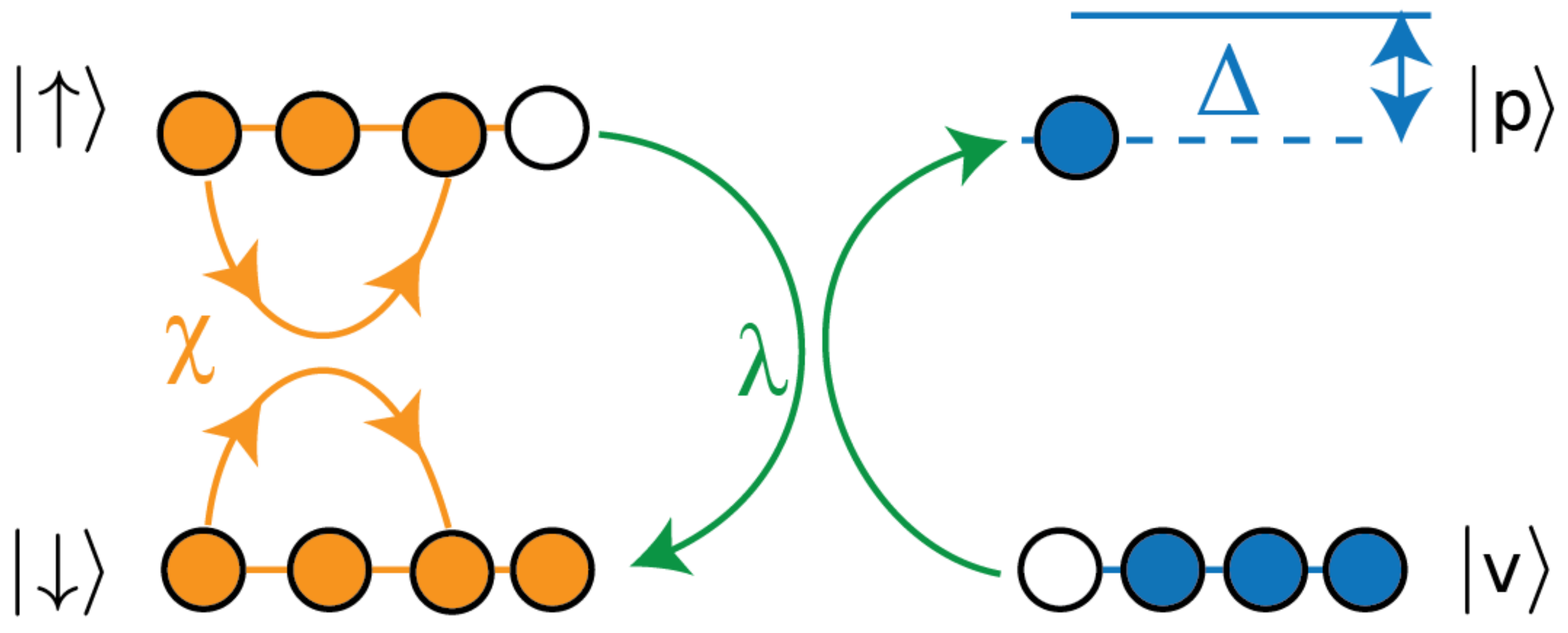


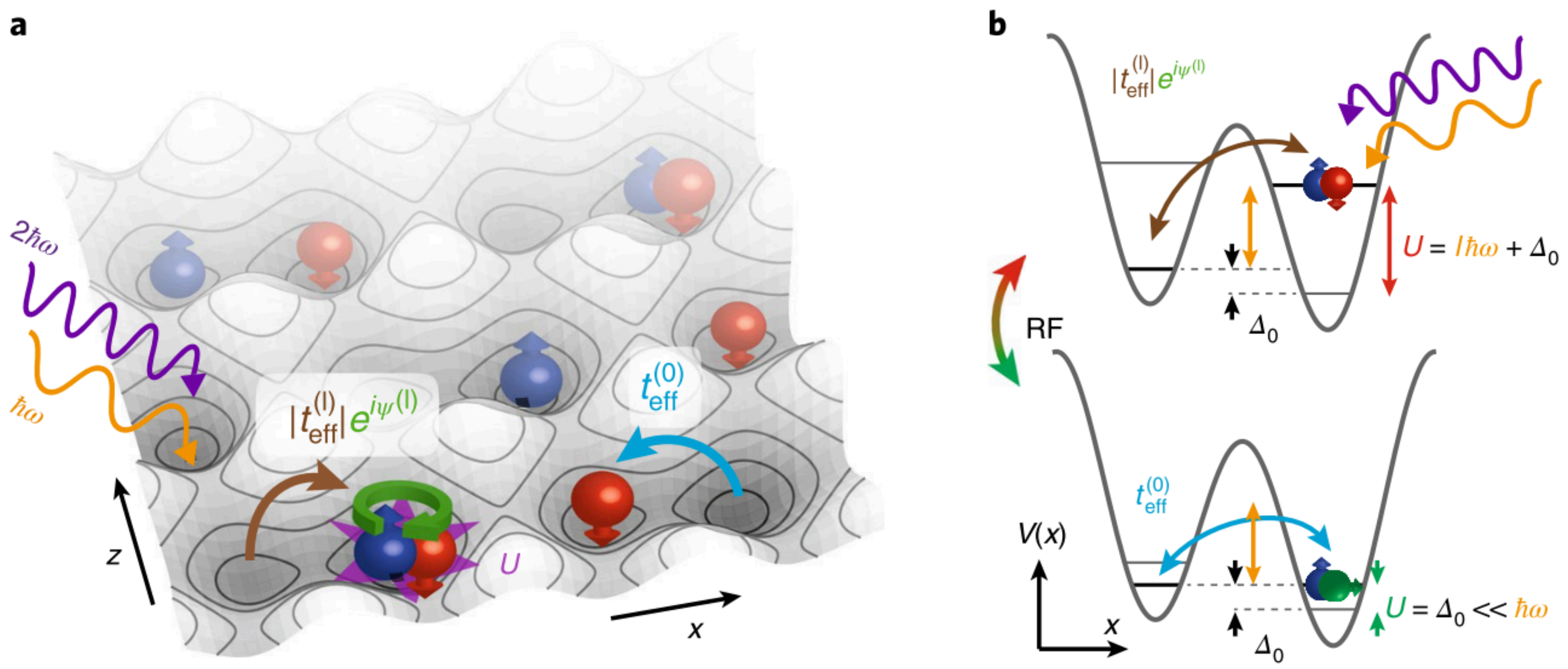
B. Yang et al.,
Nature **587**, 392 (2020)



Mil *et al.*, Science **367**, 1128 (2020)



F. Görg et al.,
Nat. Phys. **15**, 1161 (2019).



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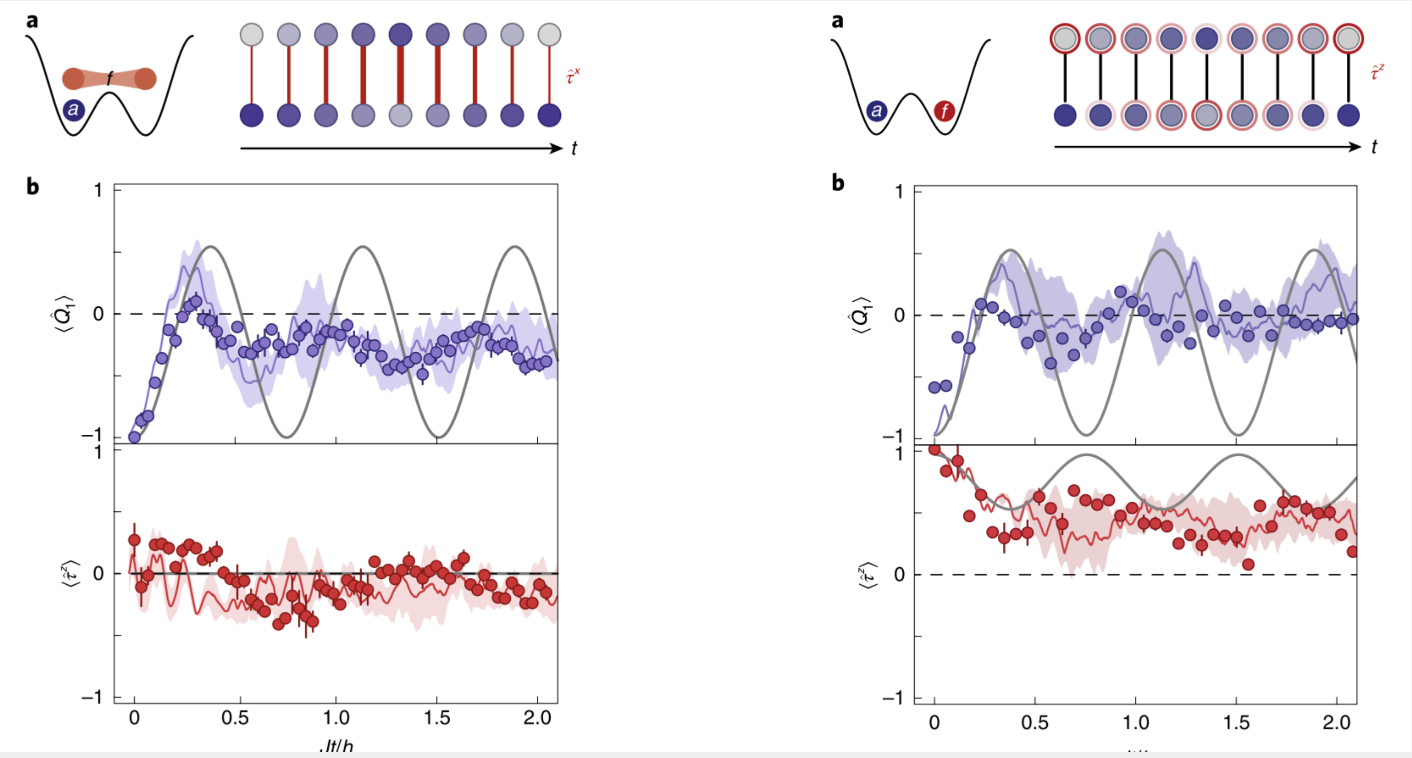
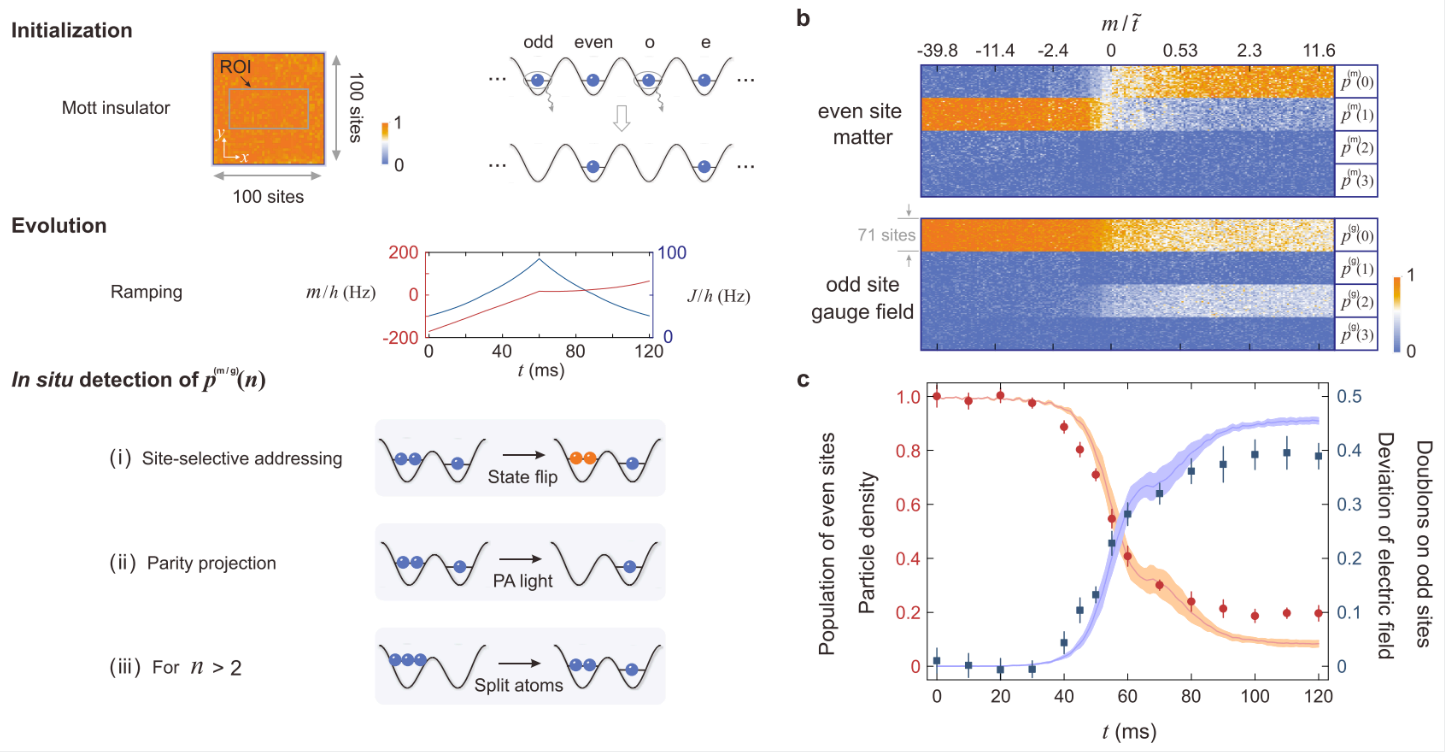
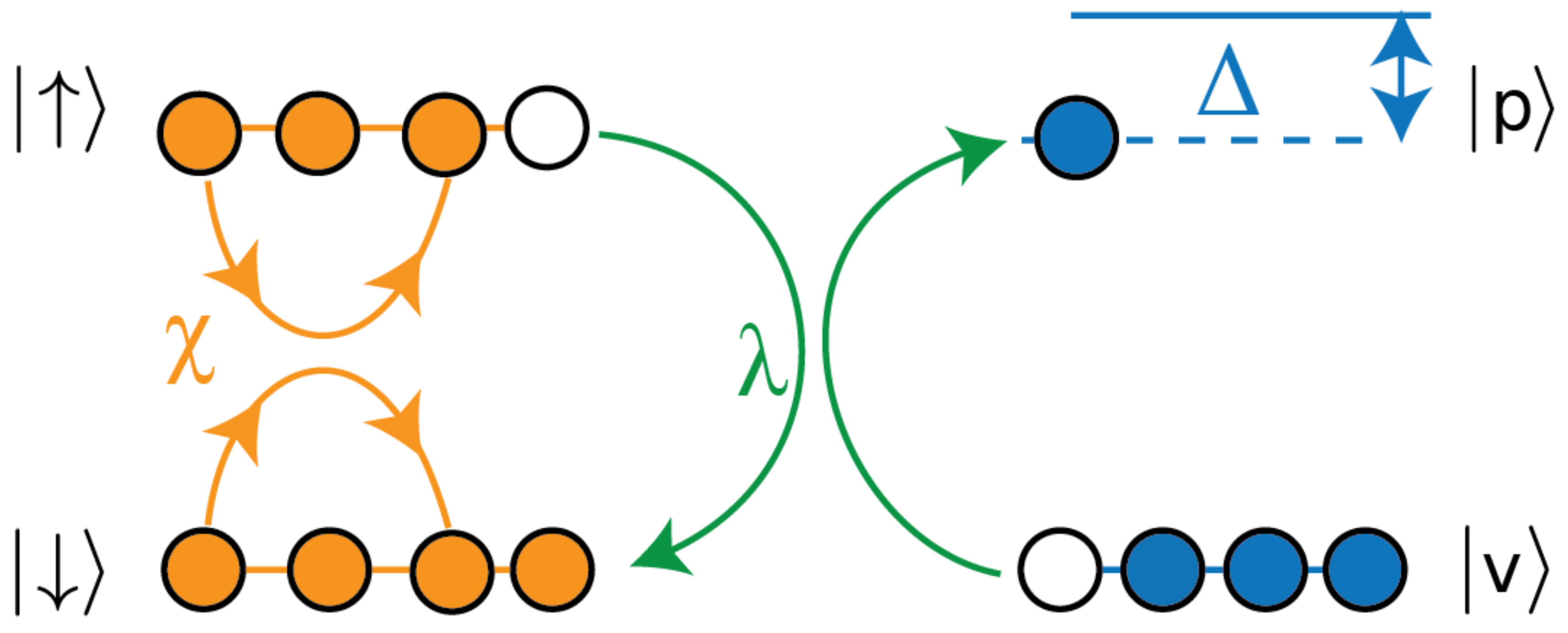


So what is going on in these experiments ?

Nature **587**, 392 (2020)



Mil *et al.*, Science **367**, 1128 (2020)



Day 1 - What are cold atoms ?

Why sodium anyways ?

Why lasers to cool down ?

What can you measure ?

What is your Hamiltonian ?

Day 2 — Strongly interacting systems

What is Bose-Hubbard ?

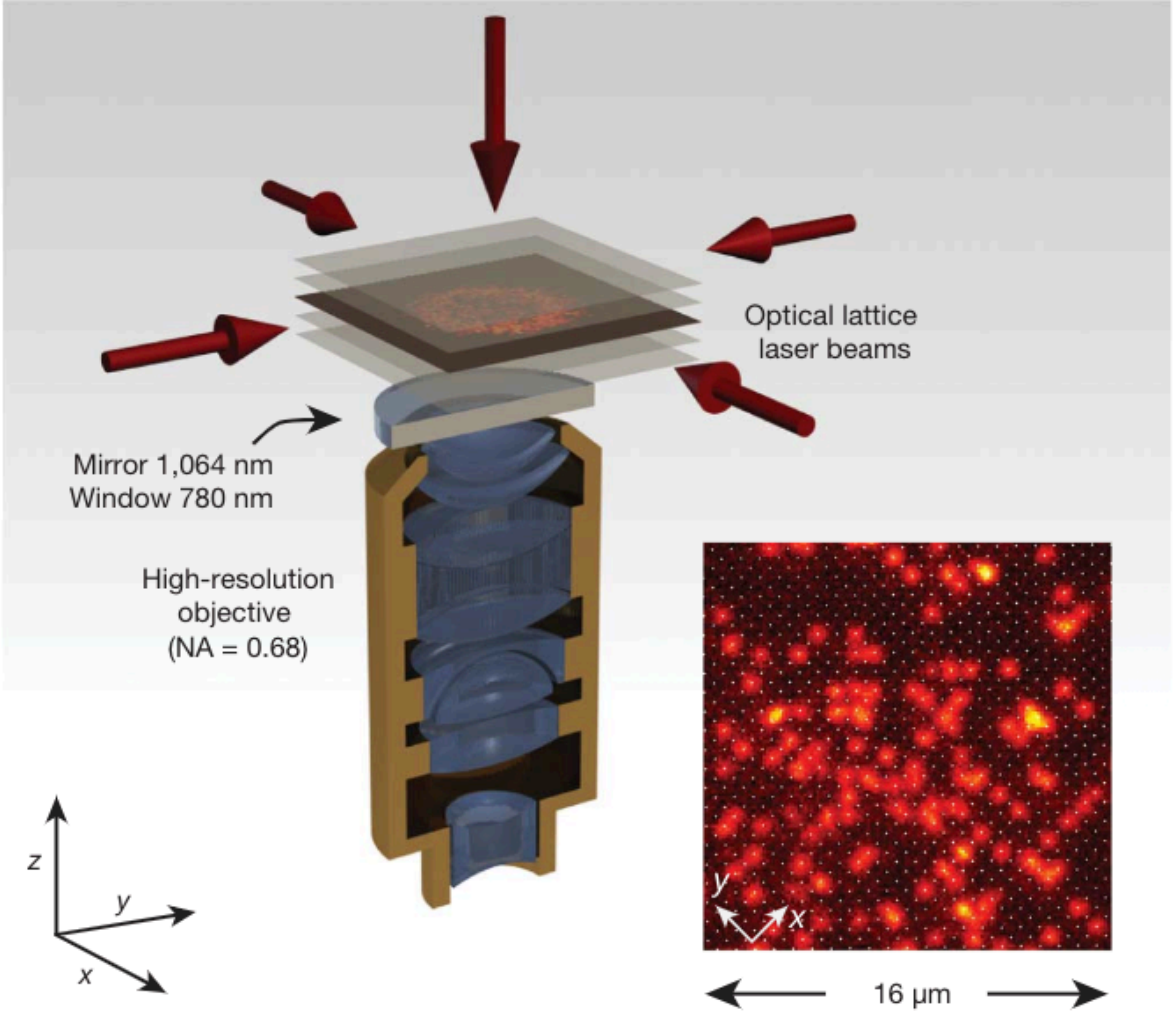
What are optical lattices

What is Fermi-Hubbard ?

What interactions do you have ?

What interactions do you have ?

What does it have to do with hep ?



From Sherson et al. Nature 2010

Day 3 — Collective spins

What is a collective spin ?

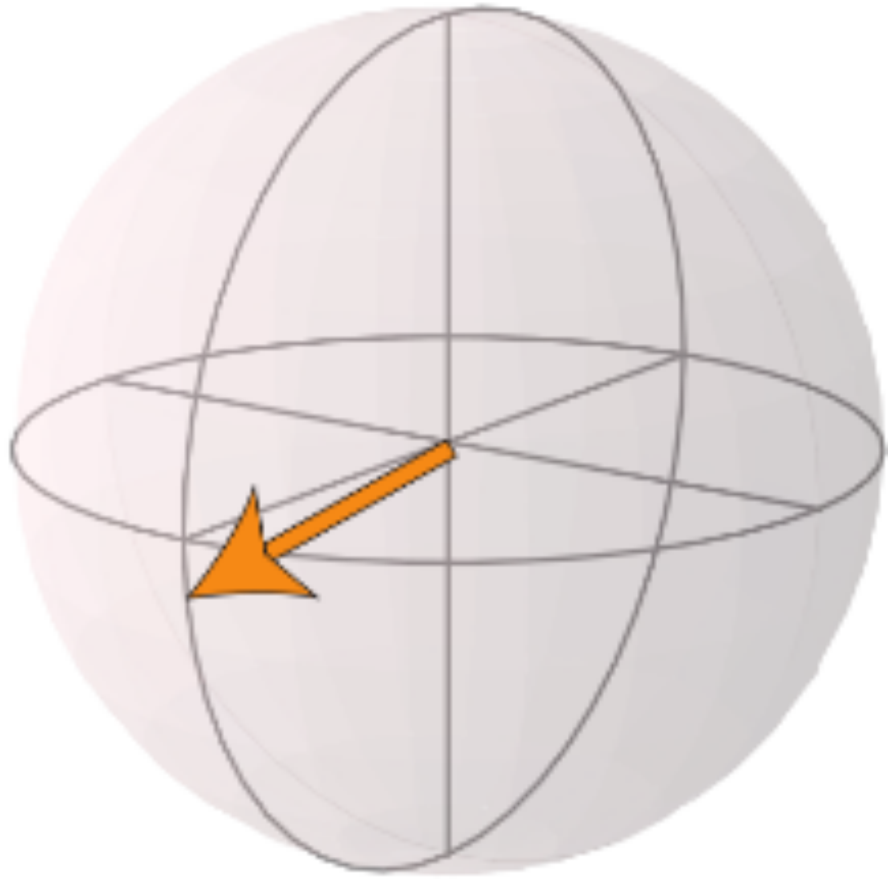
What is squeezing ?

What kind of spins can you implement ?

What is a Ramsey sequence ?

What do they have to do with hep ?

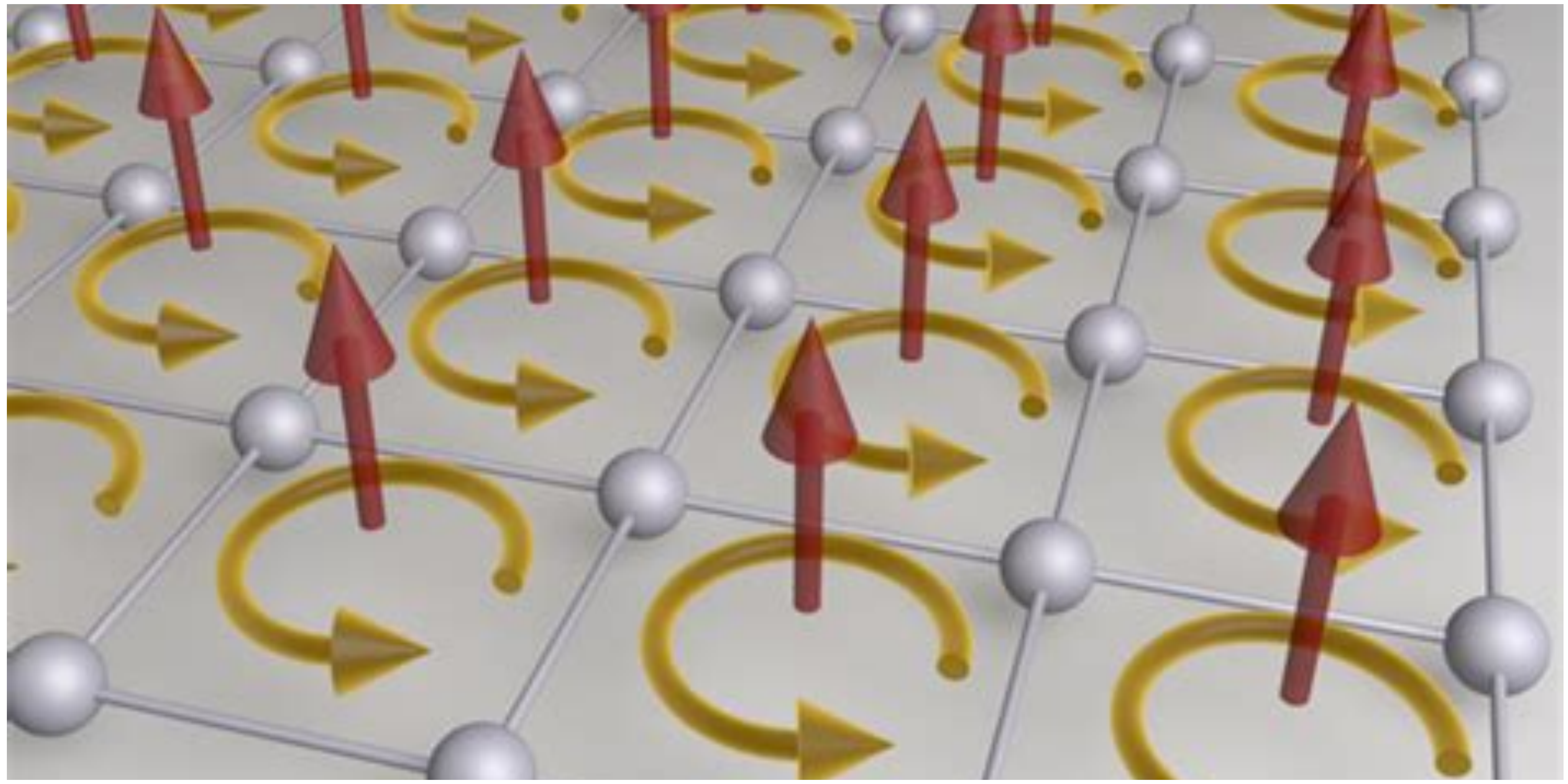
How do I realize them ?



Day 4 — Synthetic gauge fields

What is a synthetic gauge field ?

Why would you shake a system ?

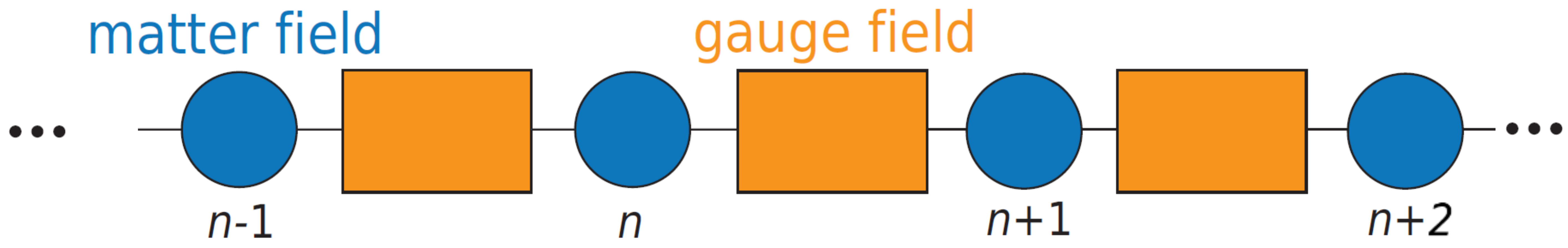


M. Aidelsburger et al. PRL 111, 185301 (2013)

What is this topology all about ?

What do they have to do with hep ?

Day 5 — Dynamical gauge fields



Higher dimensions ?

What kind of models ?

What has been done ?

What can you do right now ?


QUESTION
ASK
ask
learn
question