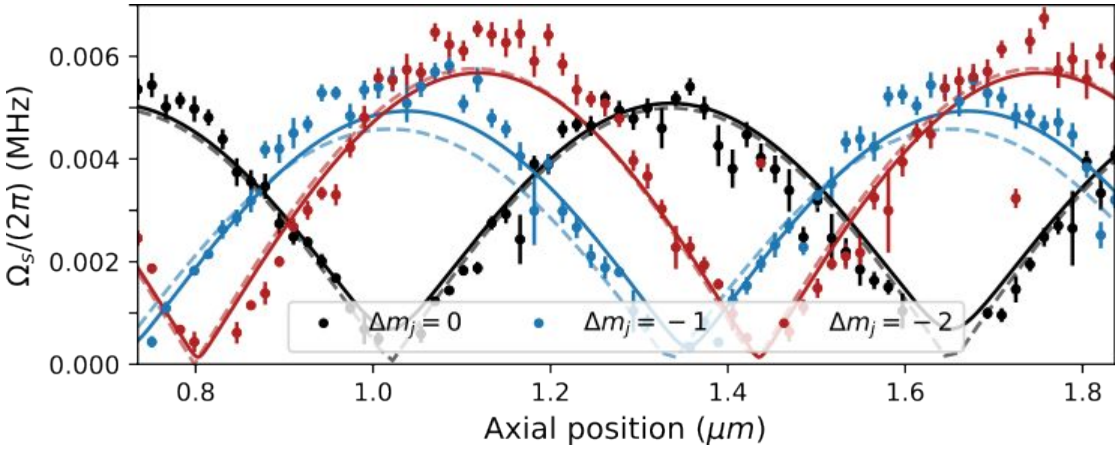
Qubit addressing in a standing wave light field from integrated photonics

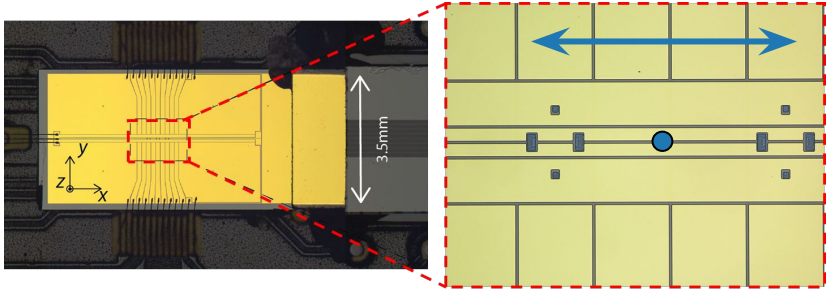
Carmelo Mordini
Trapped Ions Quantum Information
ETH Zurich



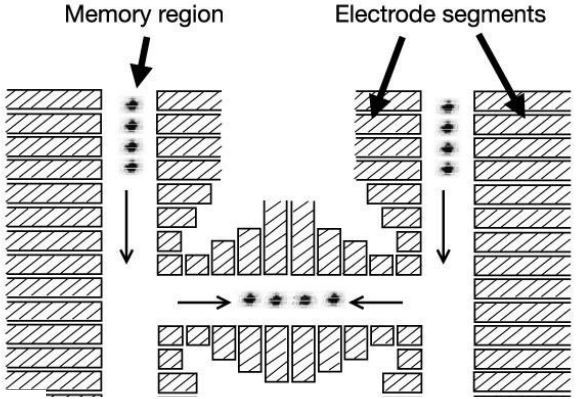
Surface traps

Surface traps (Quantum CCD) distribute ions over the chip

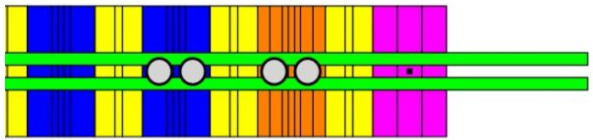
- small ion chains
- transport / splitting



Mehta et al. Nature 2020



Kielpinski et al. Nature 2002



Pino et al. Nature 2021

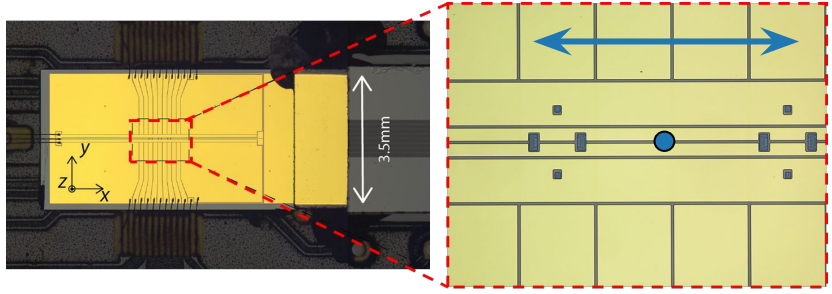
Surface traps + integrated photonics

Surface traps (QCCD)
distribute ions over the chip

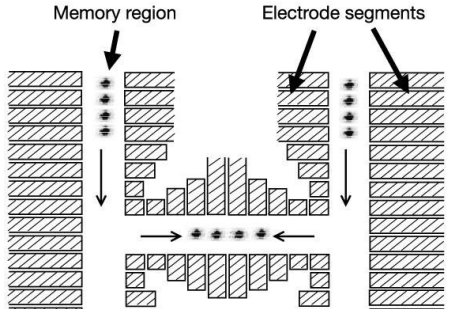
- small ion chains
- transport / splitting

Integrated photonics:
distribute light over the chip

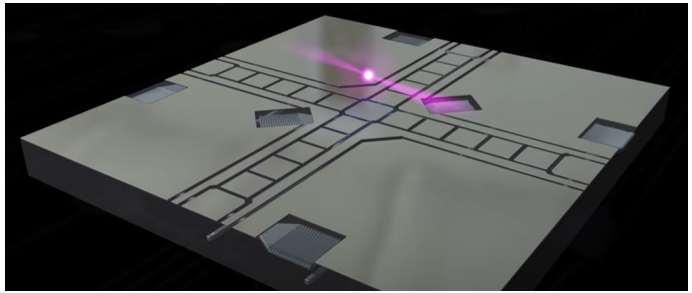
- multiwavelength
- multizone



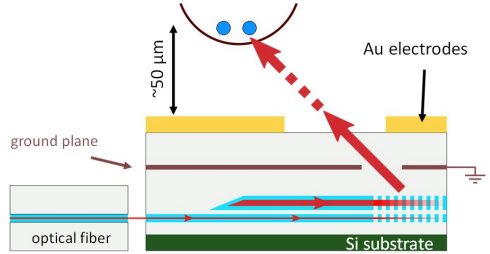
Mehta et al. Nature 2020

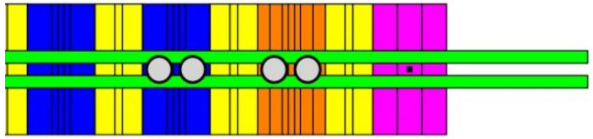


Kielpinski et al. Nature 2002

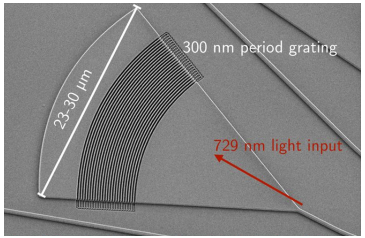


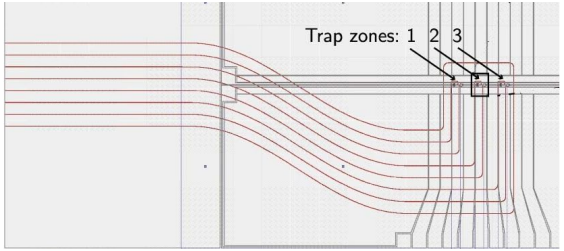
credits: MIT Lincoln Lab





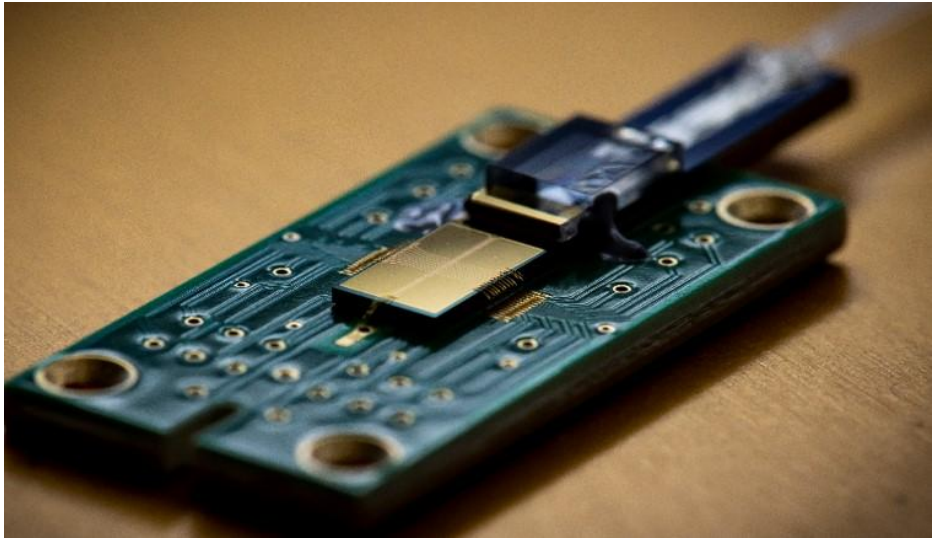
Pino et al. Nature 2021





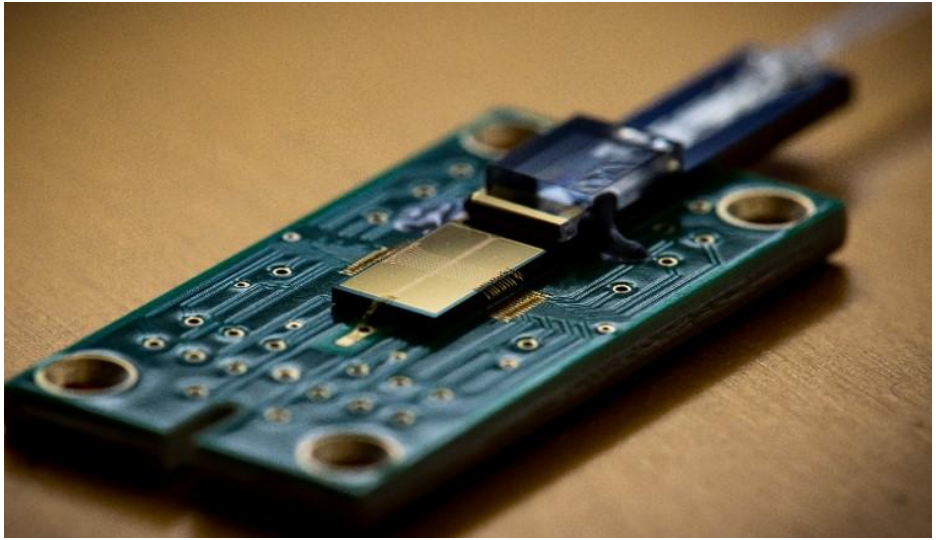
Roadmap

- Single ion operations
  Mehta et al. Nature Nanotech. 2016
- Multi-wavelength integration
  Niffenegger et al. Nature 2020
- Multi-qubit operations
  Mehta et al. Nature 2020



Roadmap

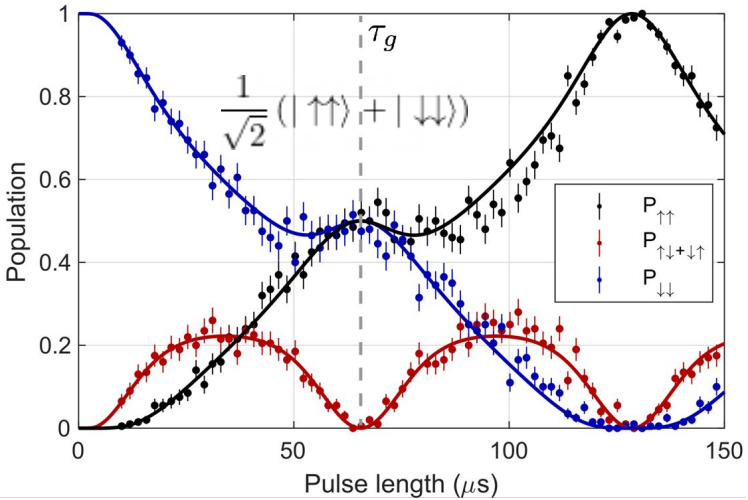
- Single ion operations
  Mehta et al. Nature Nanotech. 2016
- Multi-wavelength integration
  Niffenegger et al. Nature 2020
- Multi-qubit operations
  Mehta et al. Nature 2020
- **Engineered light beams: standing wave gate**
  Mehta et al. Proc SPIE 2019 (proposal)
- Multi-zone trapping and transport
- Multi-zone operations
- Multi-(qubit, wavelength, zone) operations

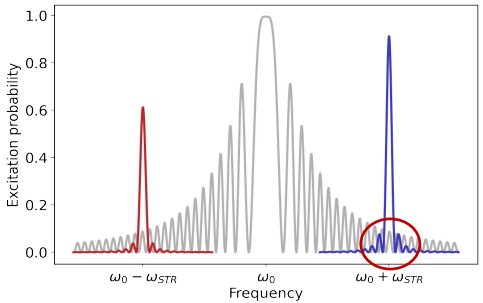


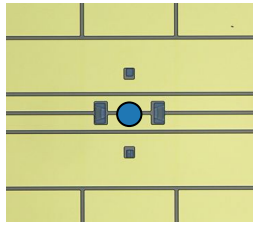
Multi-qubit operations

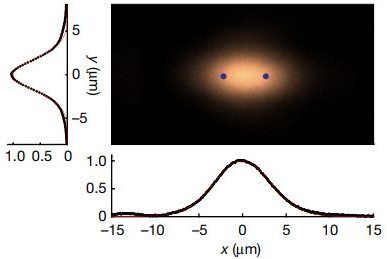
MS gate using integrated photonics

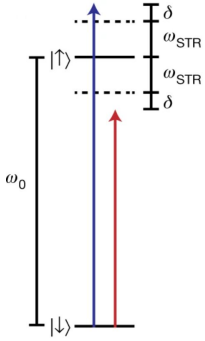
- Beam shape optimized at ions location: high intensity
- No phase noise from vibrations
- Improvement: reduce gate time
  - Requires more laser power
  - Limited by off-resonant exc. of carrier

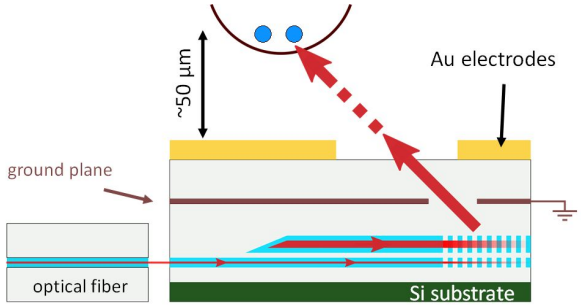










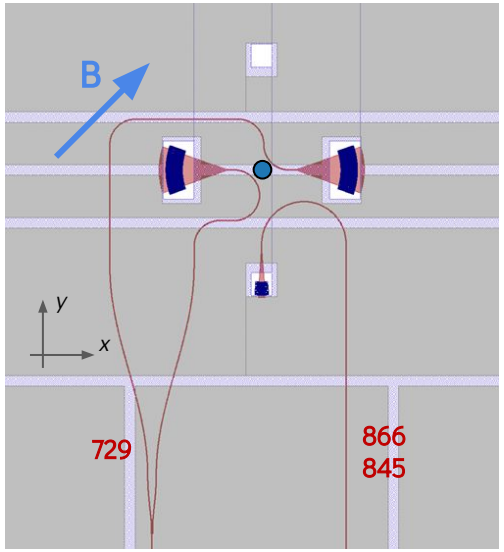


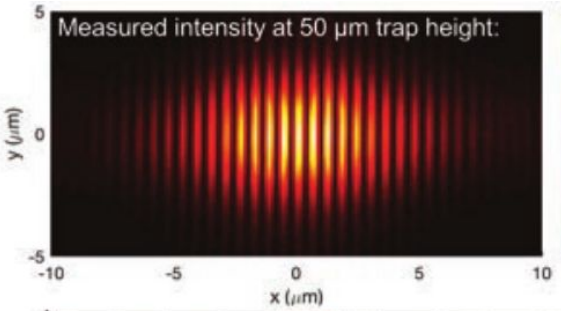
Mehta et al. Nature 2020

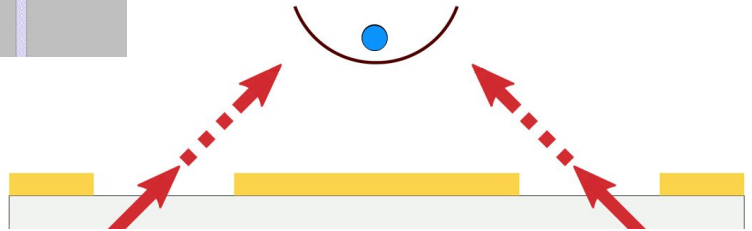
Coupling to a standing wave

$$E(\vec{r}) \propto e^{i(k_z z)} \cos(k_x x)\mathbf{e}_y$$

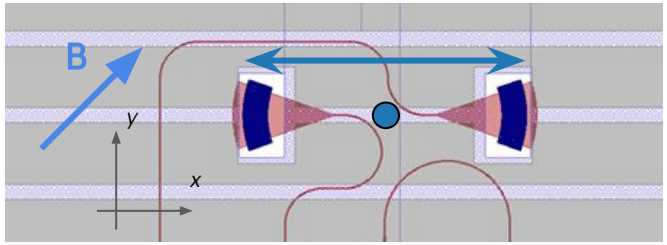
- Selectively null carrier or sidebands removing off-resonant coupling
  Mehta et al. Proc SPIE 2019
  upcoming talk by Sebastian Saner
- Requires stable positioning of the ion in the interference pattern
  - In a cavity
    Mundt et al, PRL (Innsbruck, 2002)
  - In a stabilized optical lattice
    Schmiegelow et al, PRL (Mainz, 2016)
    upcoming talk by Oana Bazavan
- With integrated beams
  - Standing/running wave
  - Passive stability

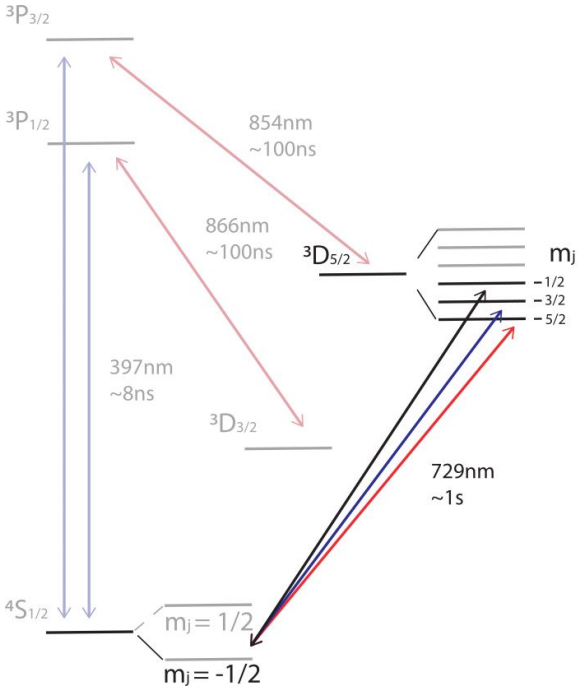




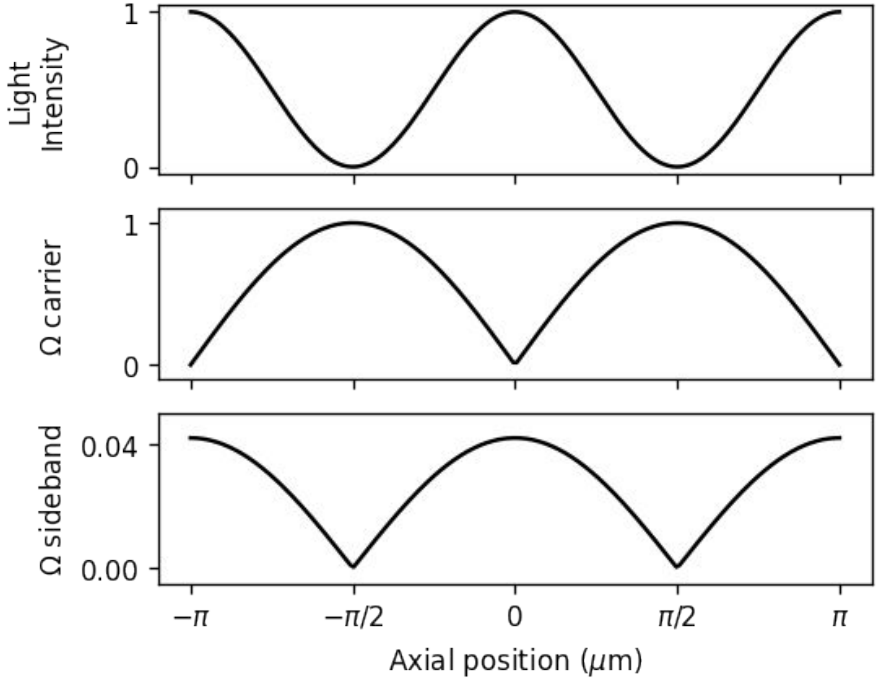


Standing wave: Rabi couplings





$$E(\vec{r}) \propto e^{i(k_z z)} \cos(k_x x)\mathbf{e}_y$$

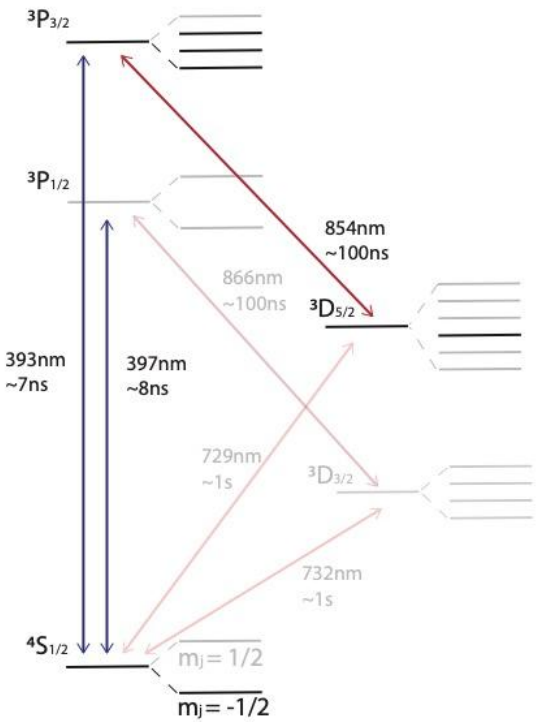


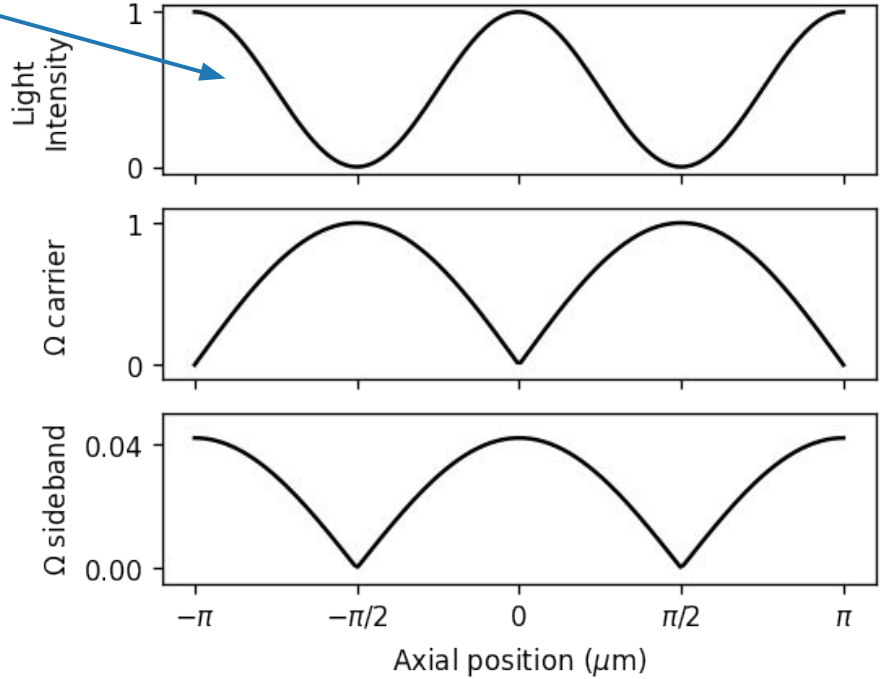
Standing wave: AC Stark shift

Dipole SS ∝ field intensity

Transitions to/from other electronic levels

$$E(\vec{r}) \propto e^{i(k_z z)} \cos(k_x x)\mathbf{e}_y$$



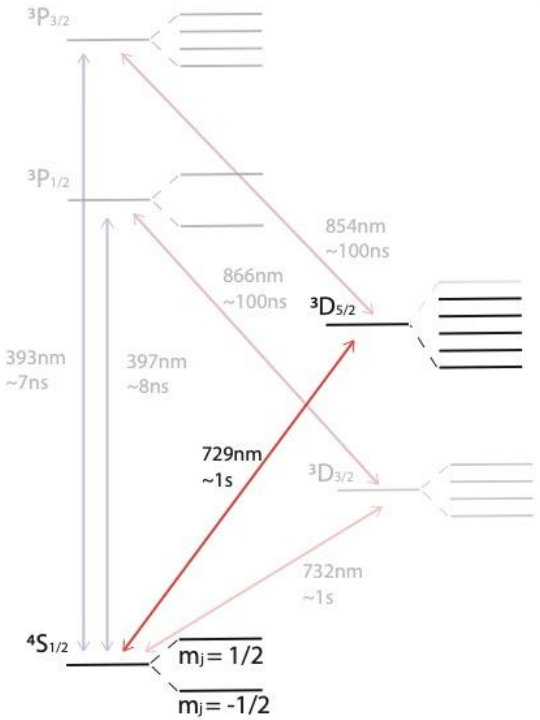


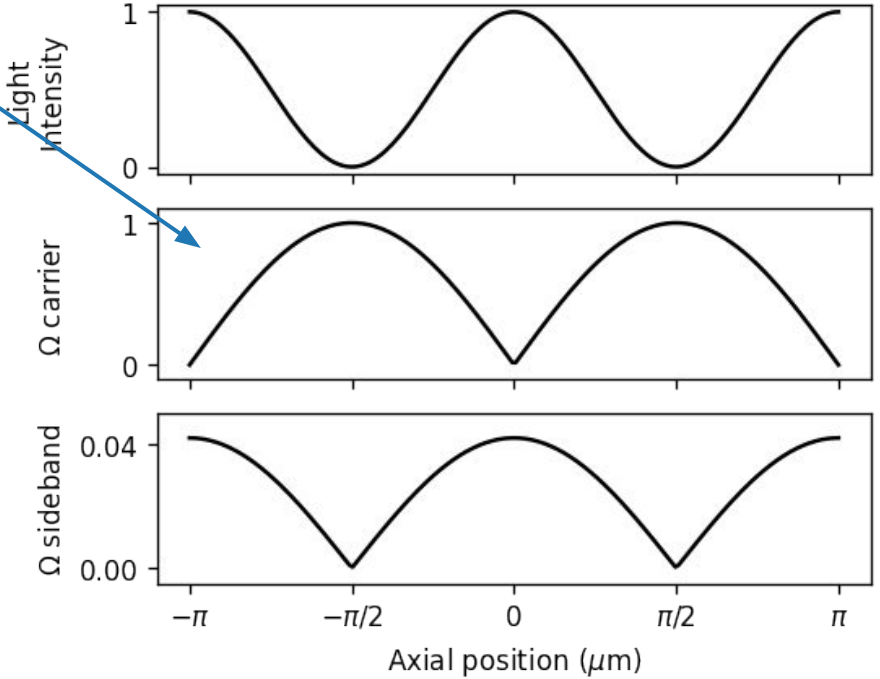
Standing wave: AC Stark shift

Quadrupole SS ∝ field gradient

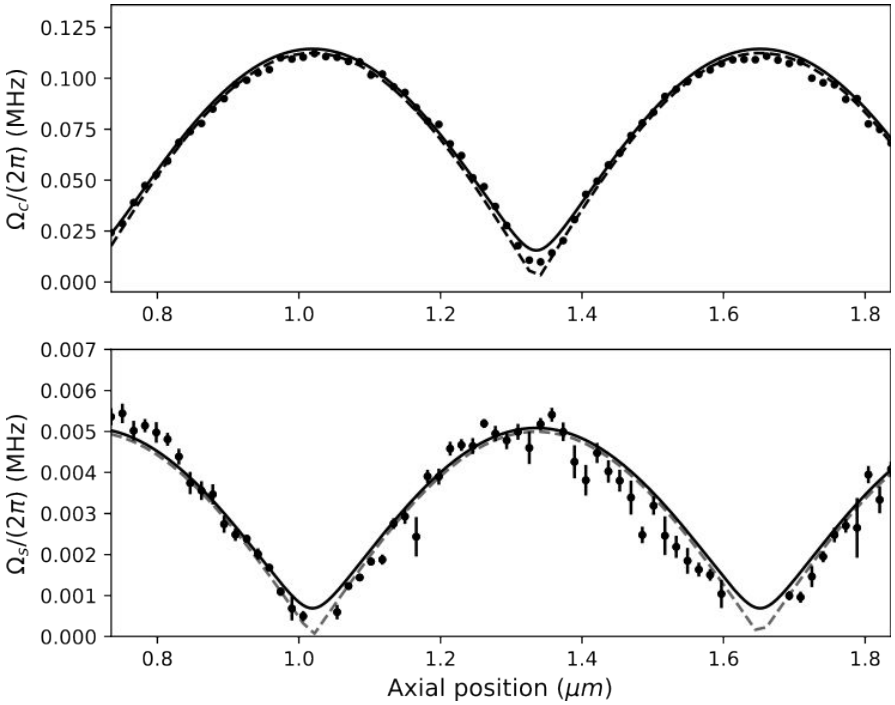
Transitions between other Zeeman sublevels

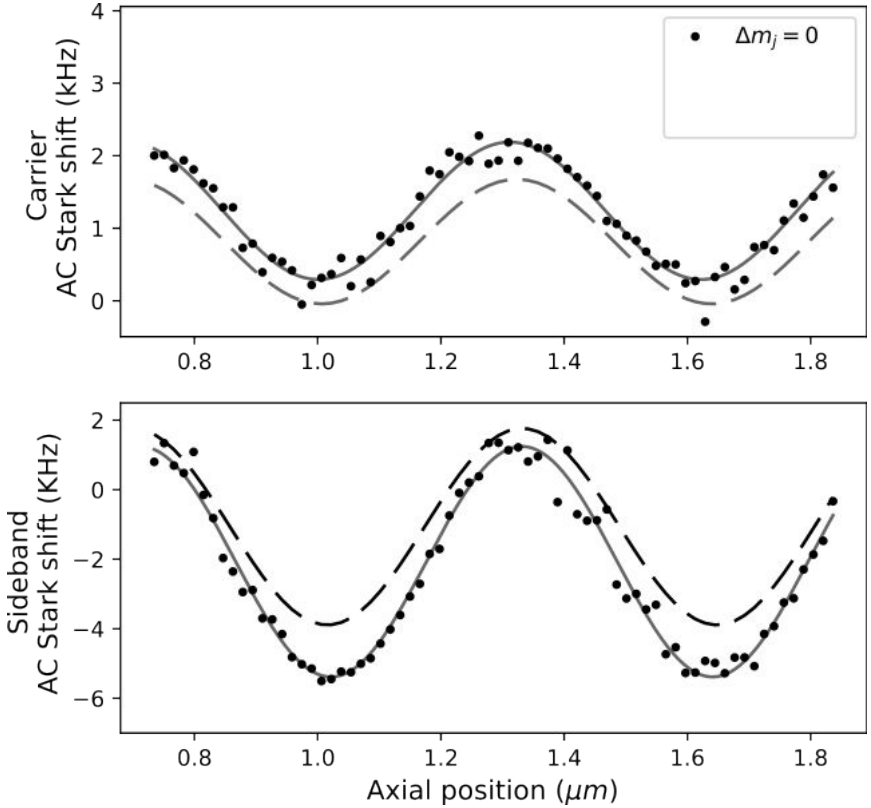
$$E(\vec{r}) \propto e^{i(k_z z)} \cos(k_x x)\mathbf{e}_y$$



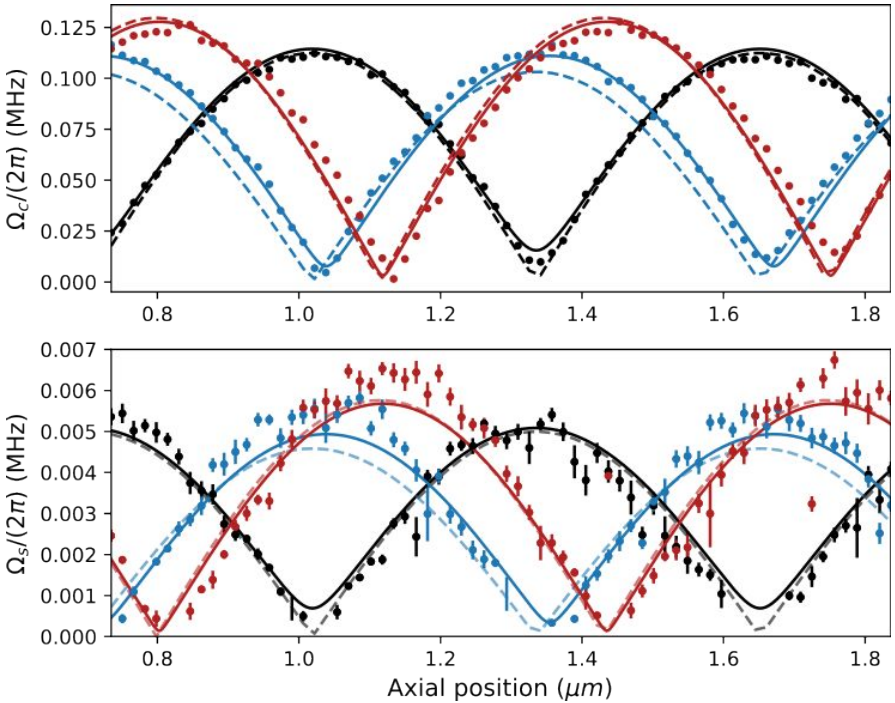


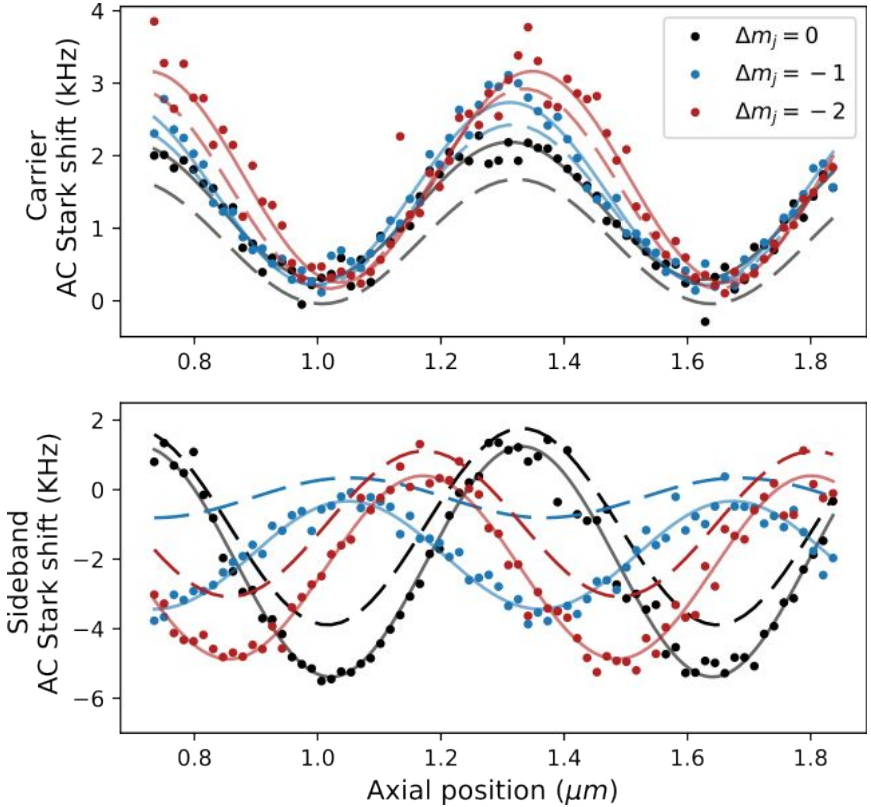
Experimental results: couplings





Experimental results: couplings

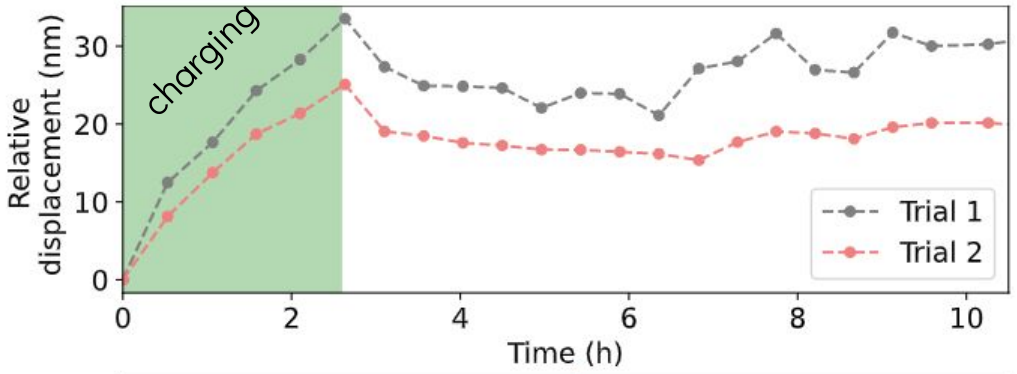




Experimental results: drift and fluctuations

Here we have a pretty precise ruler!

- Drifts: repeatedly measure ion/SW relative position from the Rabi pattern
    - (long term) shift from PI light

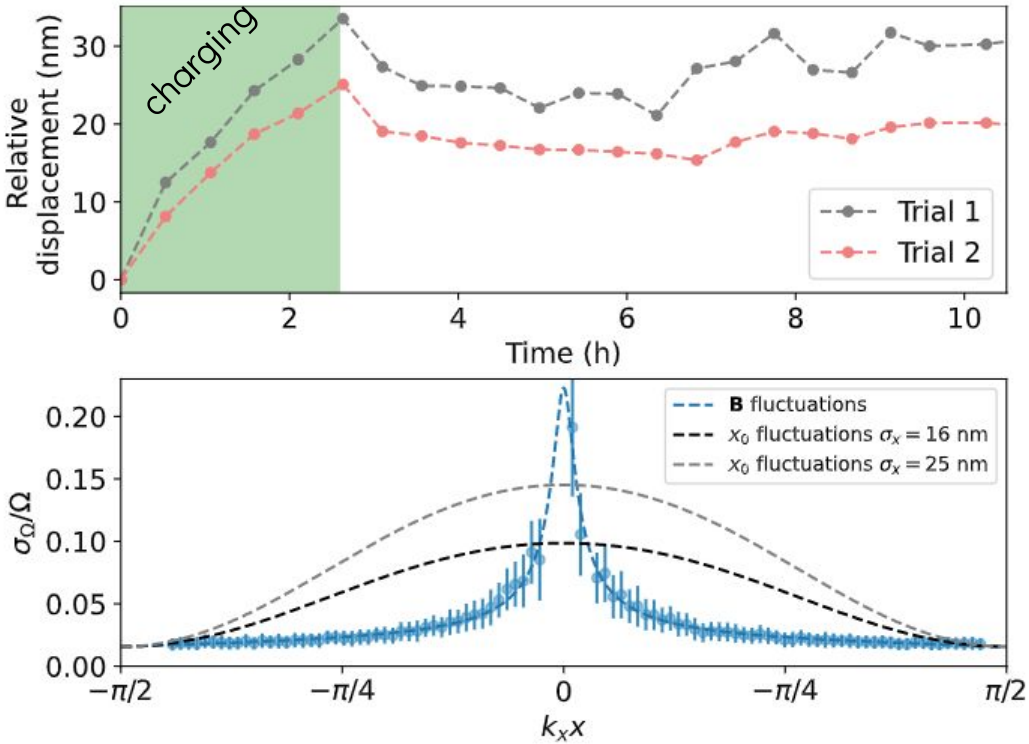


Experimental results: drift and fluctuations

Here we have a pretty precise ruler!

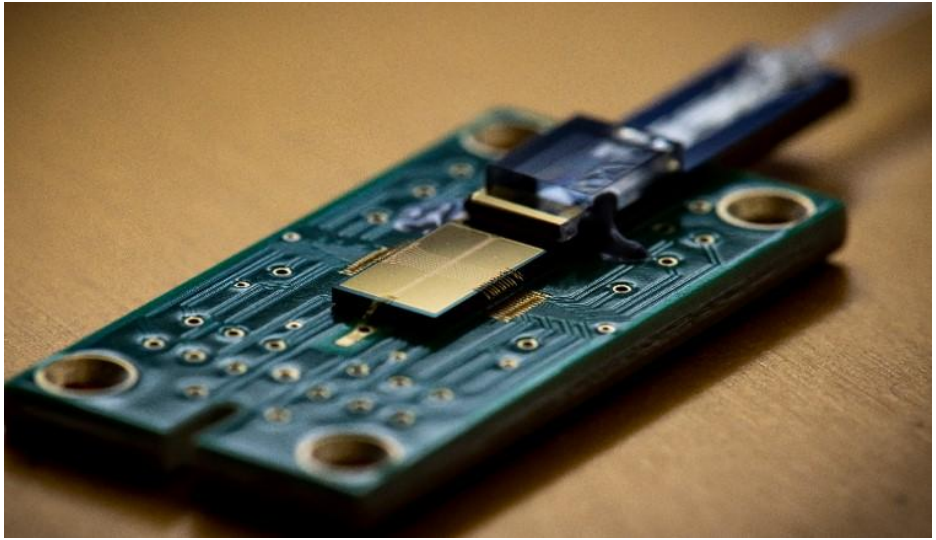
- Drifts: repeatedly measure ion/SW relative position from the Rabi pattern
  - (long term) shift from PI light

- Noise: measure flop decay vs position
  - better explained by fluctuations in the spin orientation (B field) - vibrations?

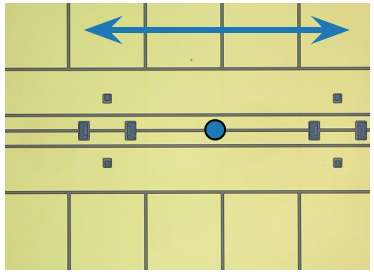


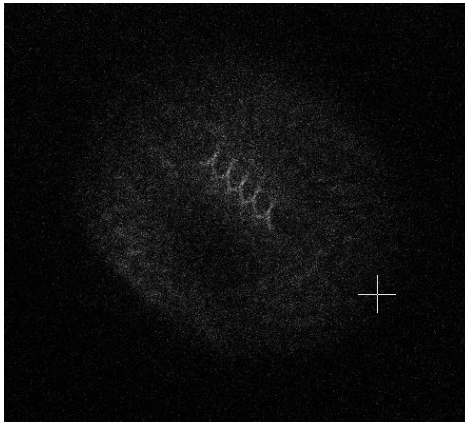
Roadmap

- Single ion operations
  Mehta et al. Nature Nanotech. 2016
- Multi-wavelength integration
  Niffenegger et al. Nature 2020
- Multi-qubit operations
  Mehta et al. Nature 2020
- Engineered light beams: standing wave gate
  Mehta et al. Proc SPIE 2019 (proposal)
- **Multi-zone trapping and transport**
- Multi-zone operations
- Multi-(qubit, wavelength, zone) operations

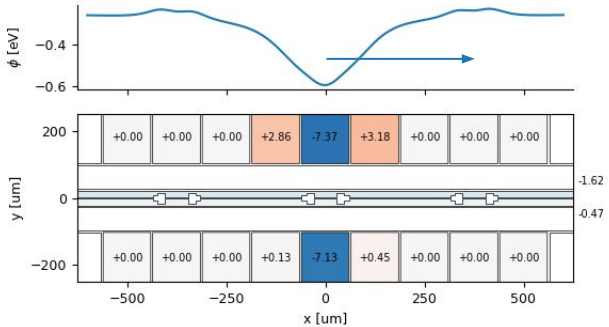


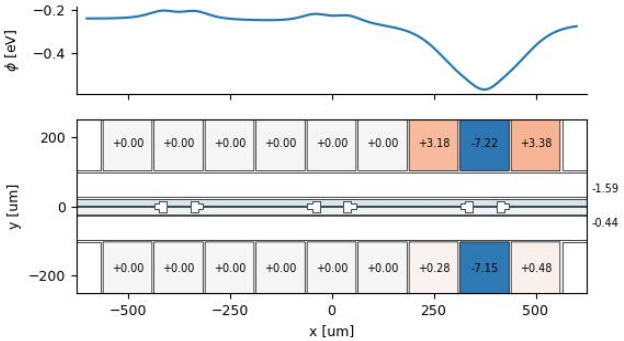
Multizone operations: multiple trapping sites

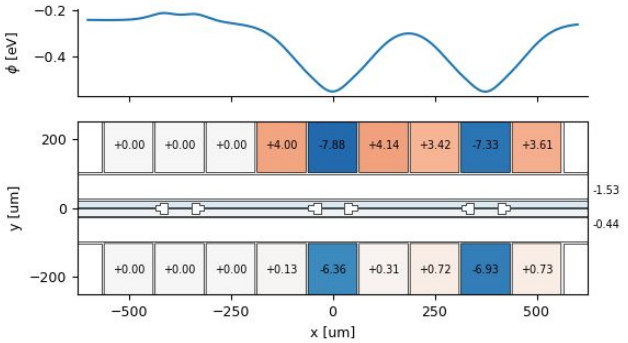




shuttling between zones

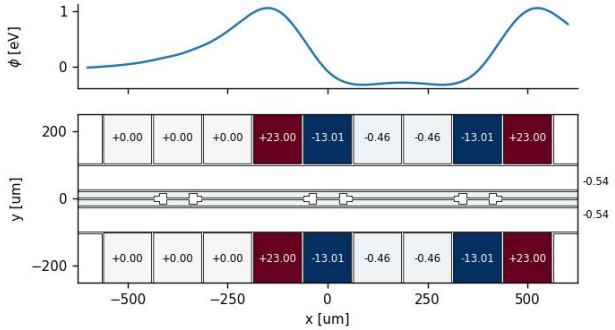




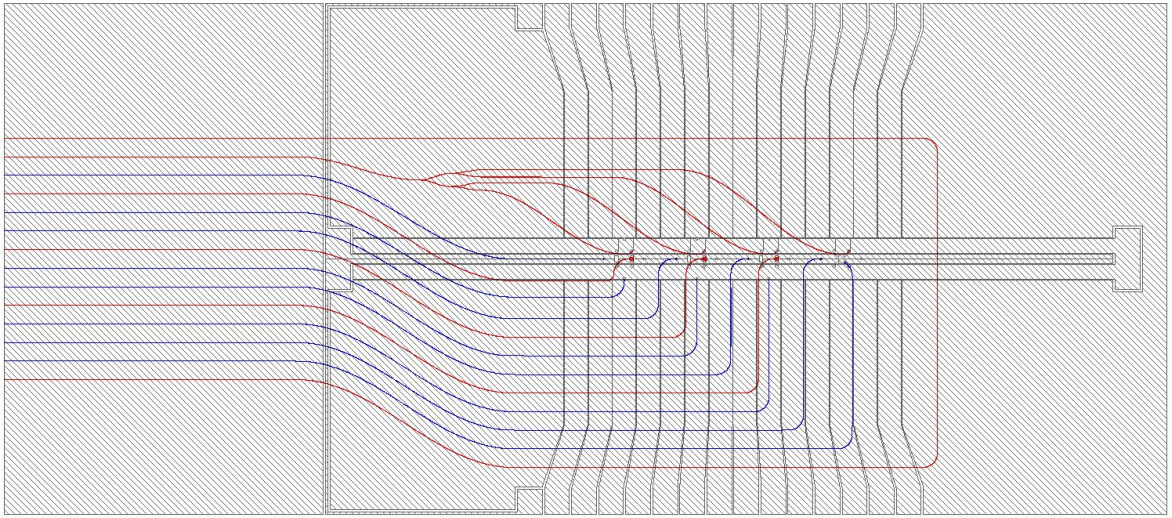


ions in multiple zones

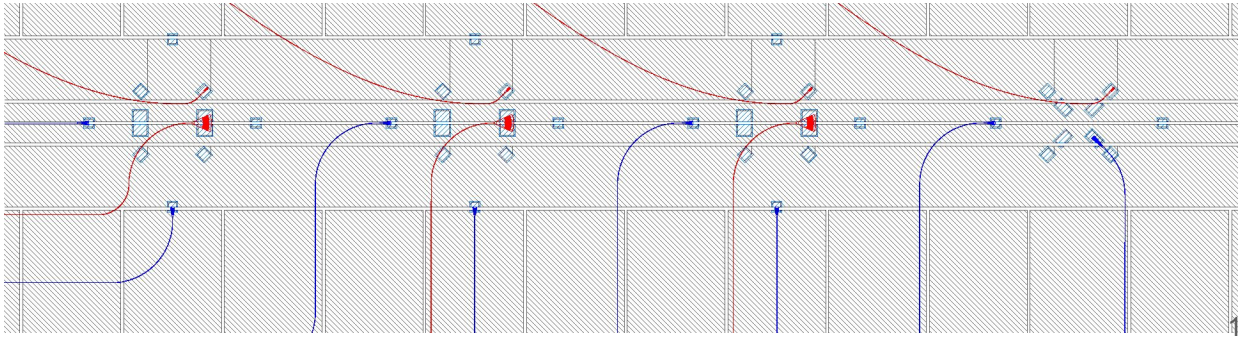
splitting/merging ion crystals



Next-gen: multizone fully integrated chip



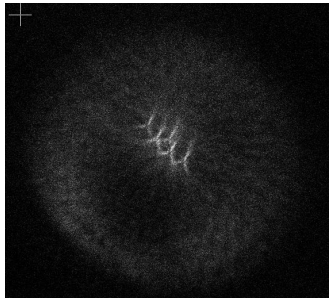
- Silicon nitride / alumina waveguides
- ITO coverings
- 1 loading + 3 working zones
- integrate cooling and qubit operations

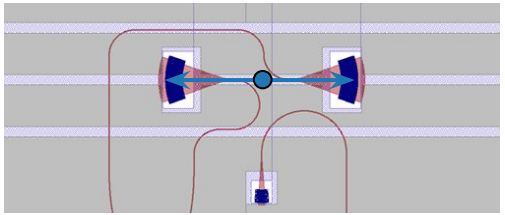


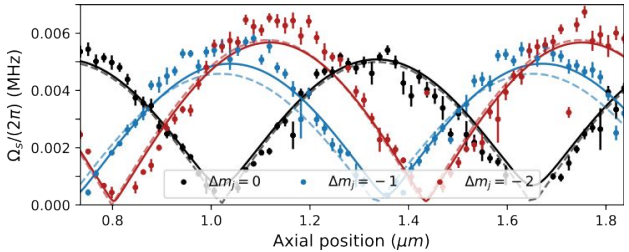
TIQI

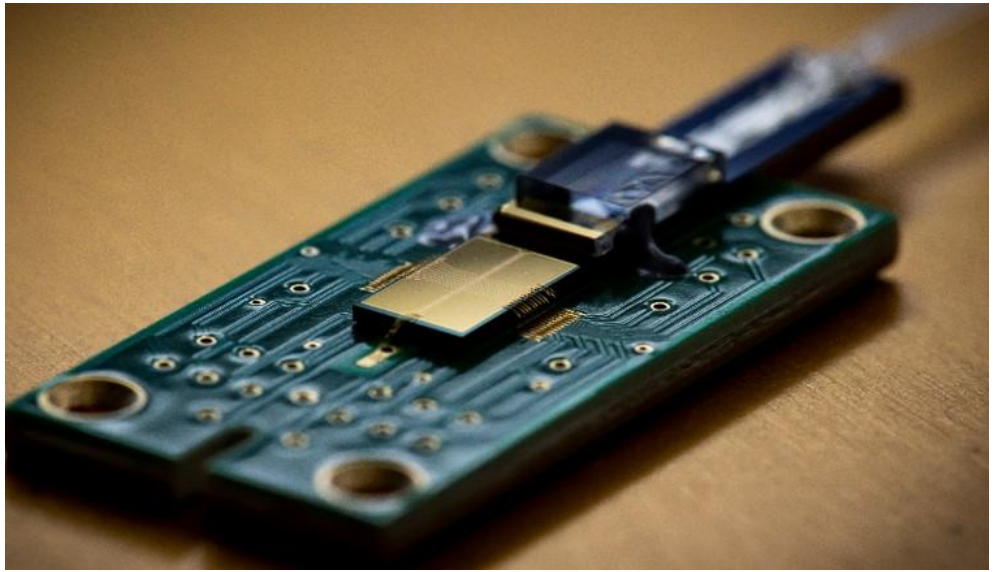

Jonathan Home
Chloé Vernière
Alfredo Ricci
Karan Mehta
CM
Daniel Kienzler
Maciej Malinowski
Chi Zhang
Halbinsel Au
14/09/2021

Thank you









cmordini@phys.ethz.ch

FNSNF

QSIT Quantum Science and Technology
National Centre of Competence in Research

ETH zürich