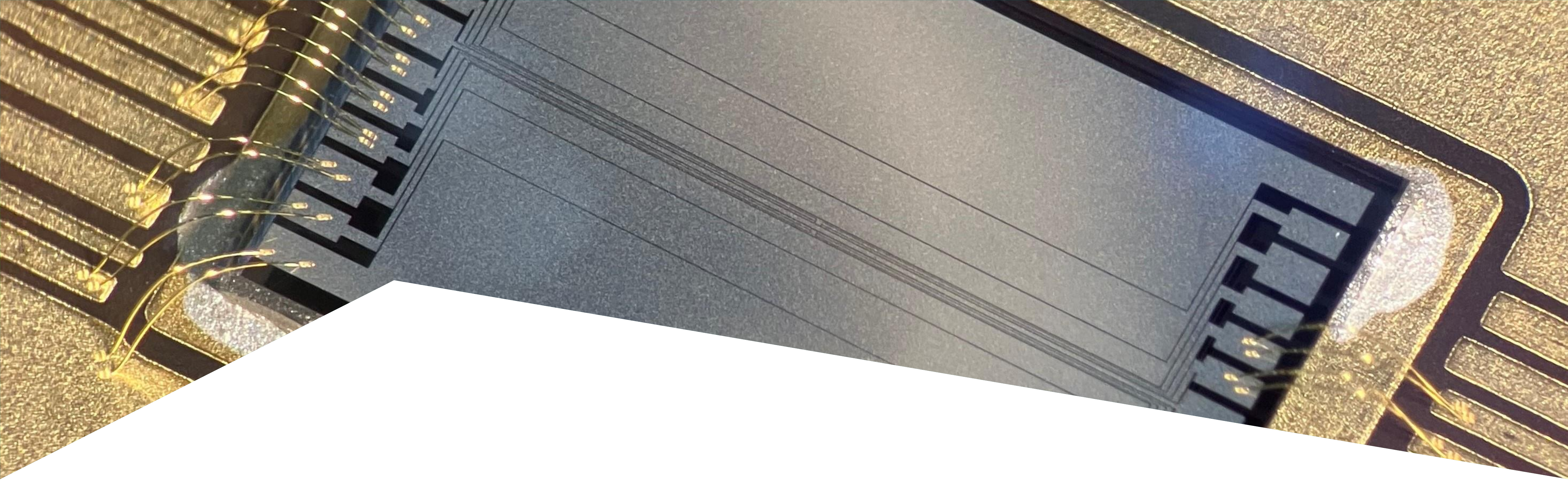

Industrially fabricated ion trap chips for double-well coupling experiments

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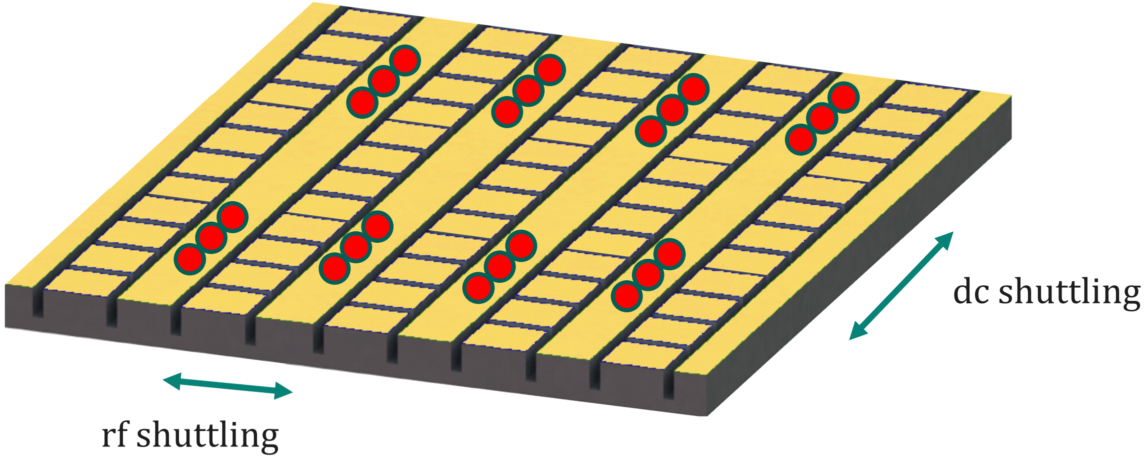
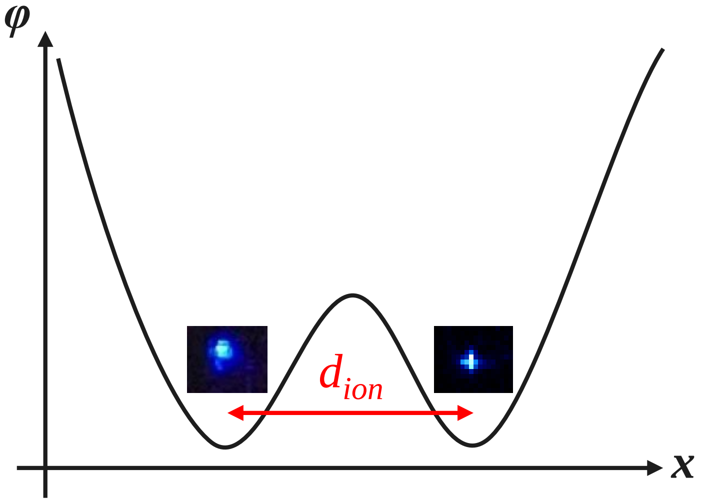
Introduction

- Ion trap chips for quantum processors
- **Goals:** Scalable architecture, industrial fabrication
- Scalable architecture: axial and radial coupling → **double-well coupling**
- Coupling strength: $\Omega_C \sim \frac{1}{\omega\, d_{ion}^3}$
- d_{ion} = *100 µm* → Ω_C = *0,09 x 2π kHz @* 1 MHz axial
- d_{ion} = *30 µm* → Ω_C = *3.3 x 2π kHz @* 1 MHz axial

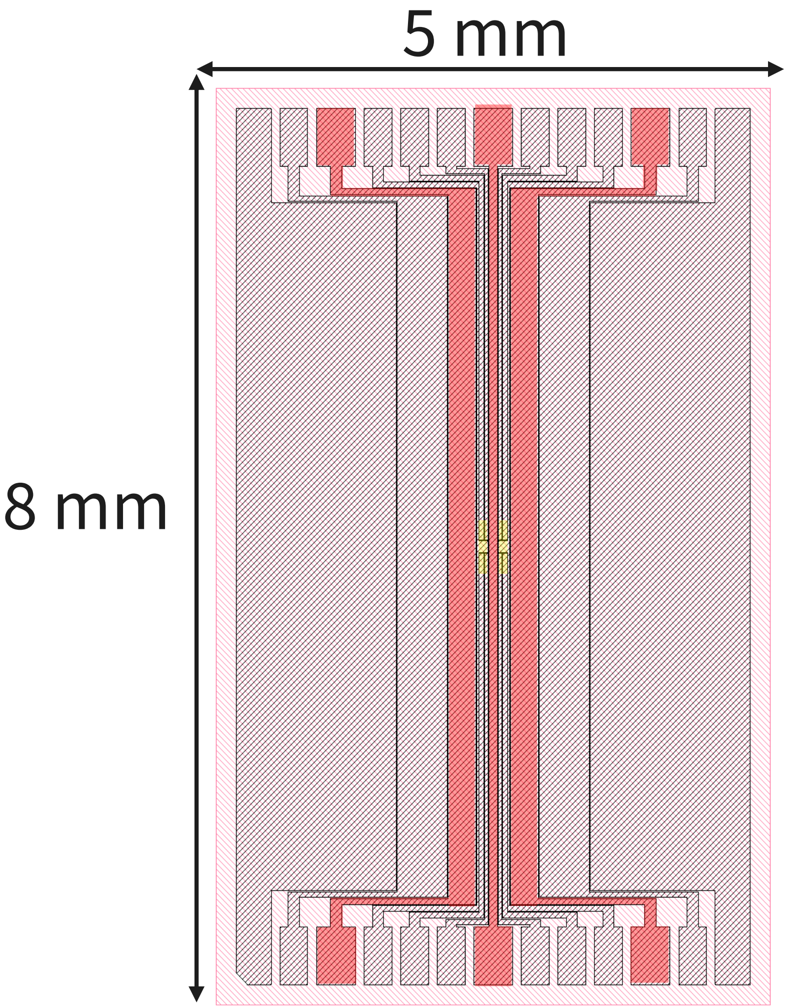


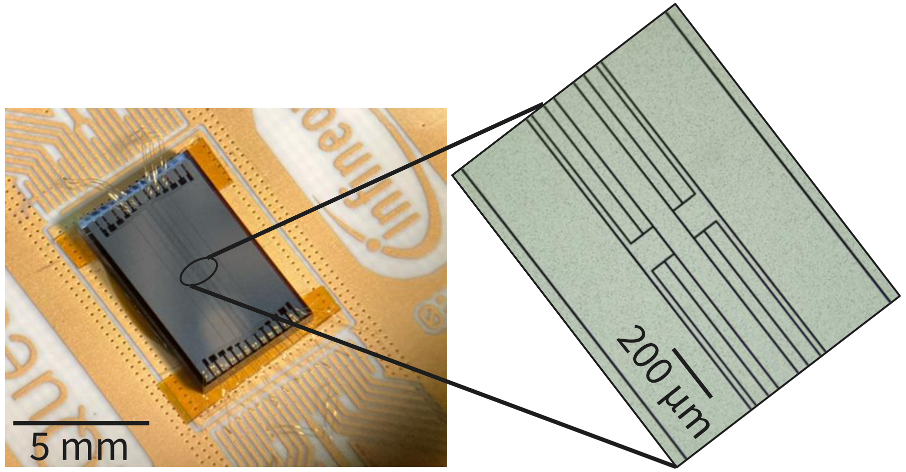
P. Holz, S. Auchter *et al.*, Adv. Quant. Technol. **3** (2020)

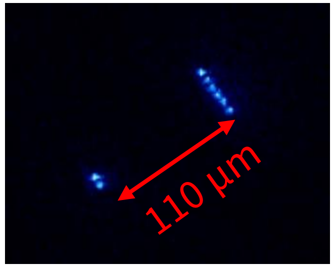


Tested devices

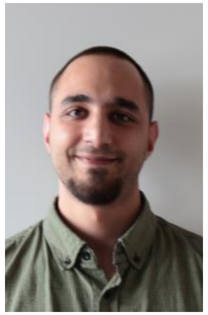
Quattro stagioni trap (4S)







- rf shuttling experiments
- 2 trapping sites
- Single metal layer trap
- Fused Silica and Sapphire substrate
- 110 µm ion-ion distance
- 130 µm ion-surface distance



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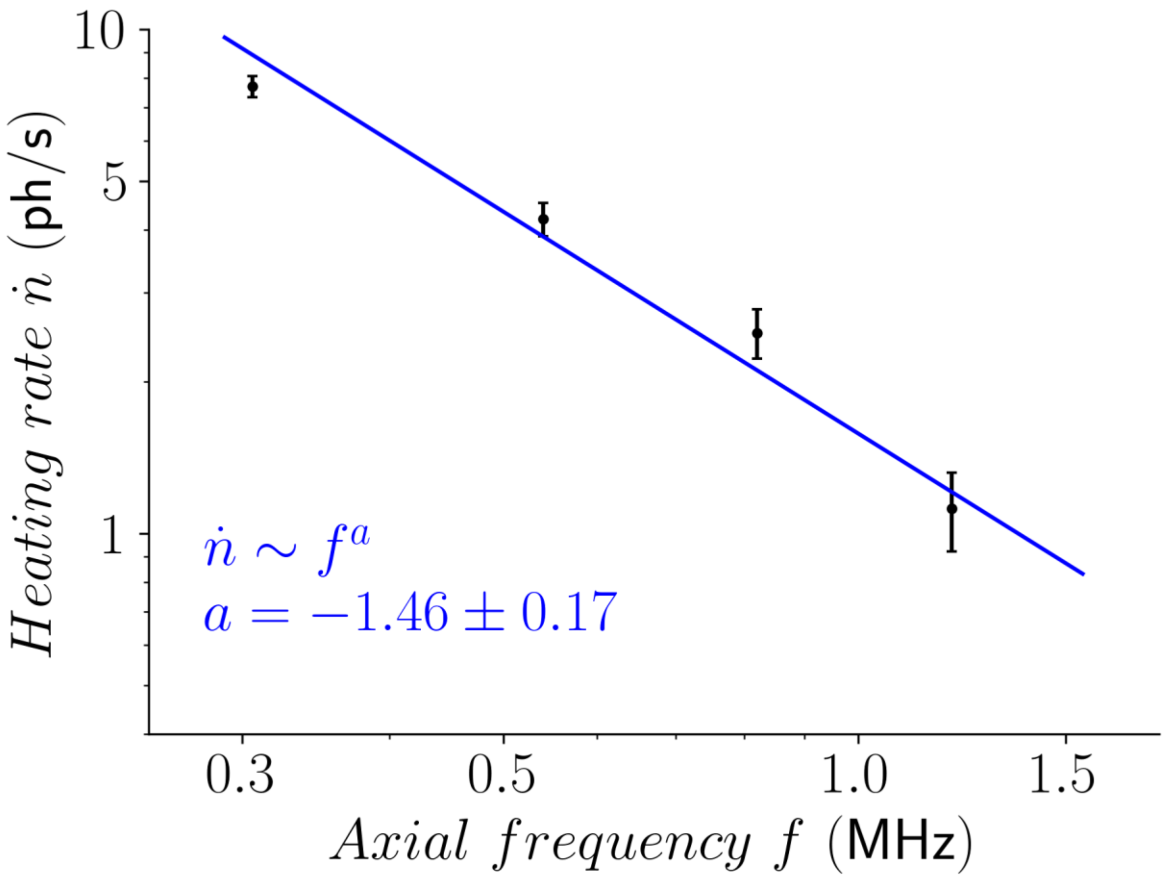
Quattro stagioni trap (4S) - results



- Reliably traps ions
- Heating rate of **1.1 ± 0.2 ph/s** @ 1.2 MHz axial

  → suitable for experiments
- rf shuttling experiments

Due stagioni trap (2S) - idea

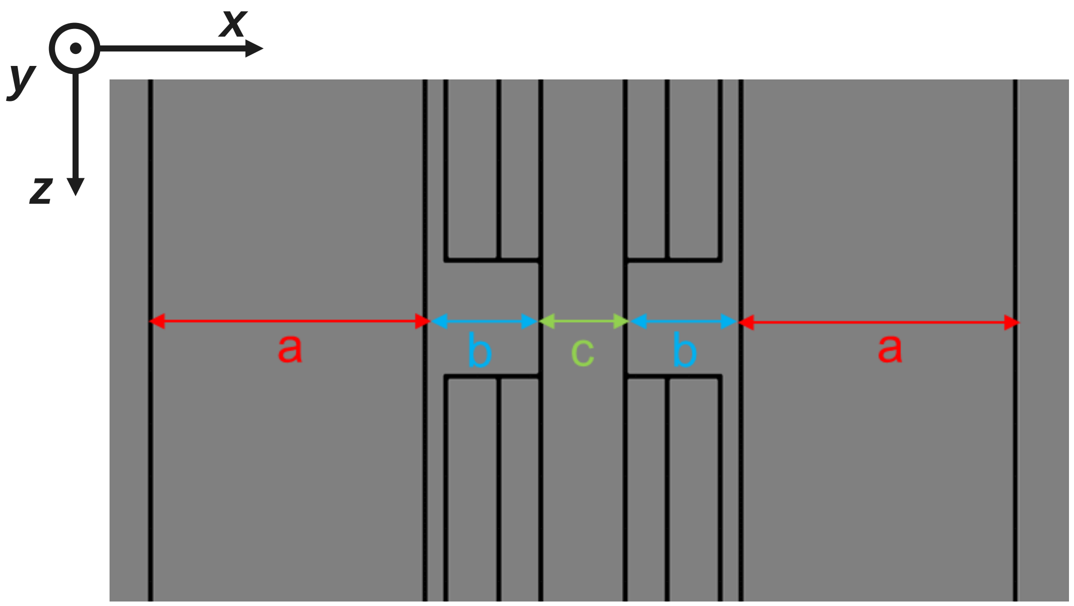
- Lower ion-ion distance → higher coupling rate

- Vary electrode size ratios with trade-off between ion height, trap efficiency κ and potential depth.

$$\varphi(x,y,t) = \frac{\kappa\, U_{\mathrm{RF}}}{2y_0^2}\left(x^2 - y^2\right)\cos\left(\Omega_{\mathrm{RF}} t\right)$$

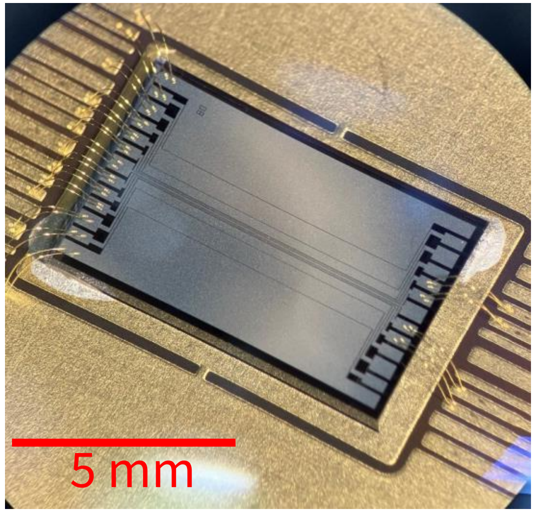
- Optimize trap efficiency κ(a, b, c) for given (d_{ion}, y_0)

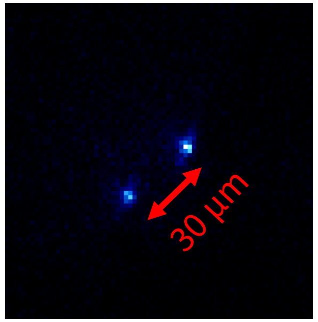
- Analytic simulations → check by FEM



Trap:	a (µm)	b (µm)	c (µm)	κ (%)
4S	255	115	75	17.6
2S/80	214	63	42	10.0

Due stagioni trap (2S) – heating rates

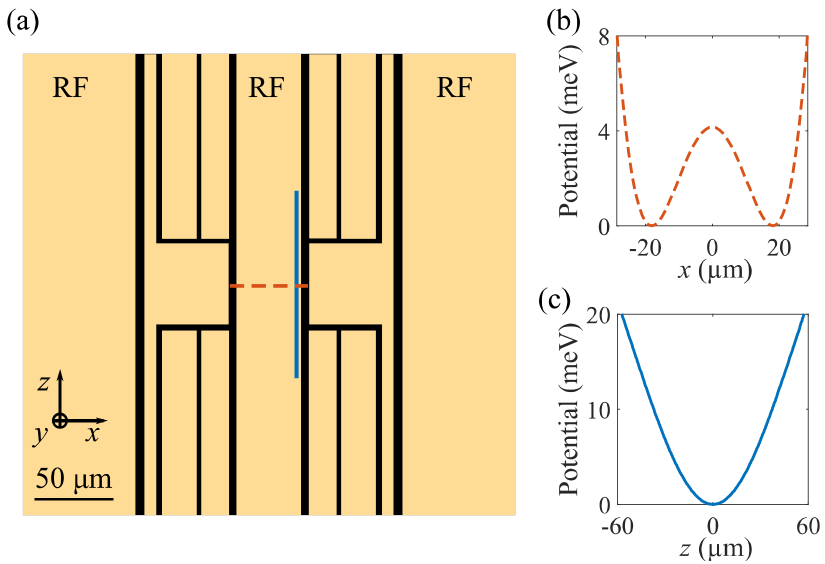




Trap site:	Axial frequency (MHz)	Heating rate (phonons/s)
left	0.5	~20
	1	~5
right	0.5	~20

– 30 µm ion-ion distance, 80 µm ion height

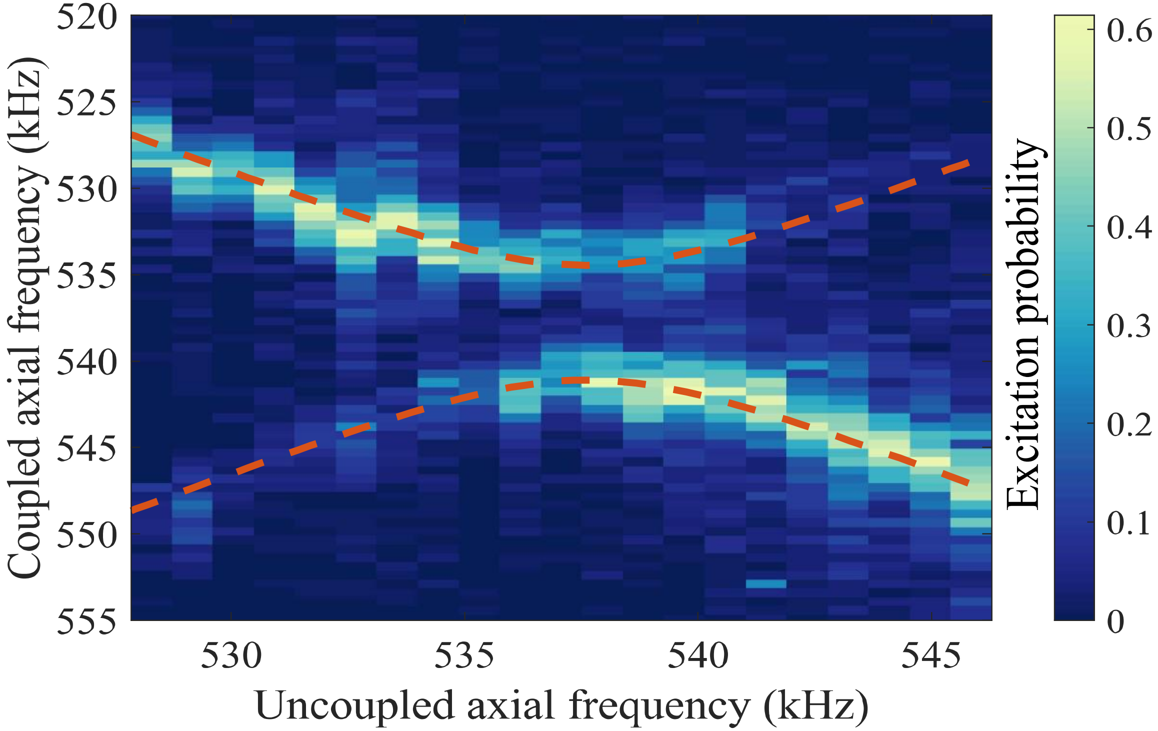
– Fused Silica substrate, Aluminum electrodes



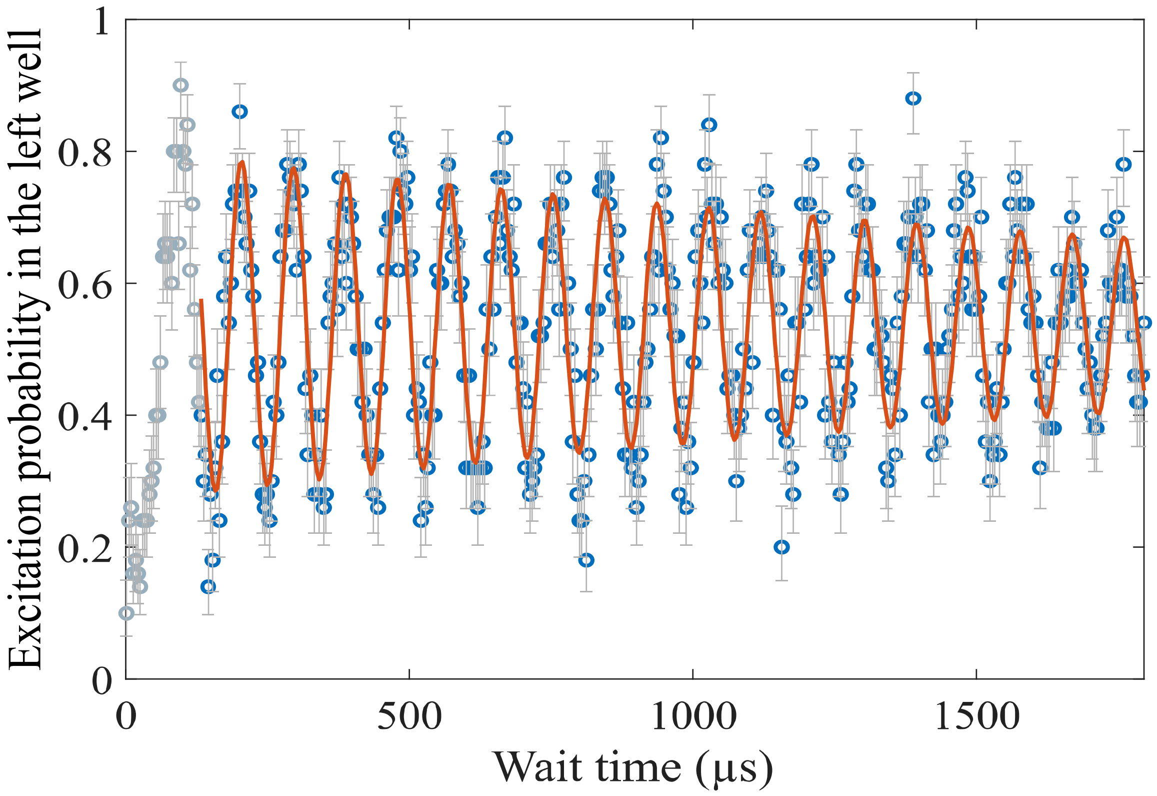
– Lower ion height than 4S, but still low heating rates

arXiv:2406.02406

Due stagioni trap (2S) – radial coupling

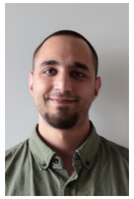


M. Valentini, M. van Mourik *et al.*, arXiv:2406.02406



- Radial coupling rate: ~ 6.5 kHz @ 500 kHz axial
  (2 ions per well)

- Enables radial coupling experiments and gates



Marco Valentini

Martin van Mourik

New devices

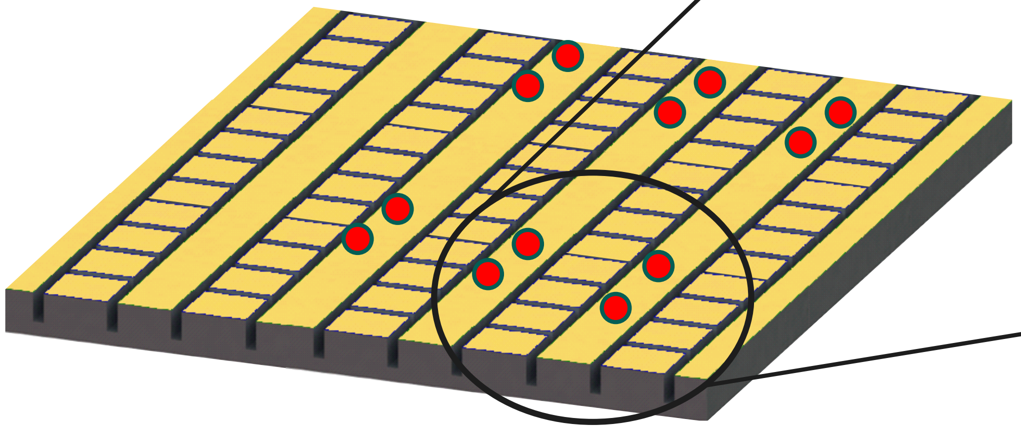
$2S^2$ trap - idea

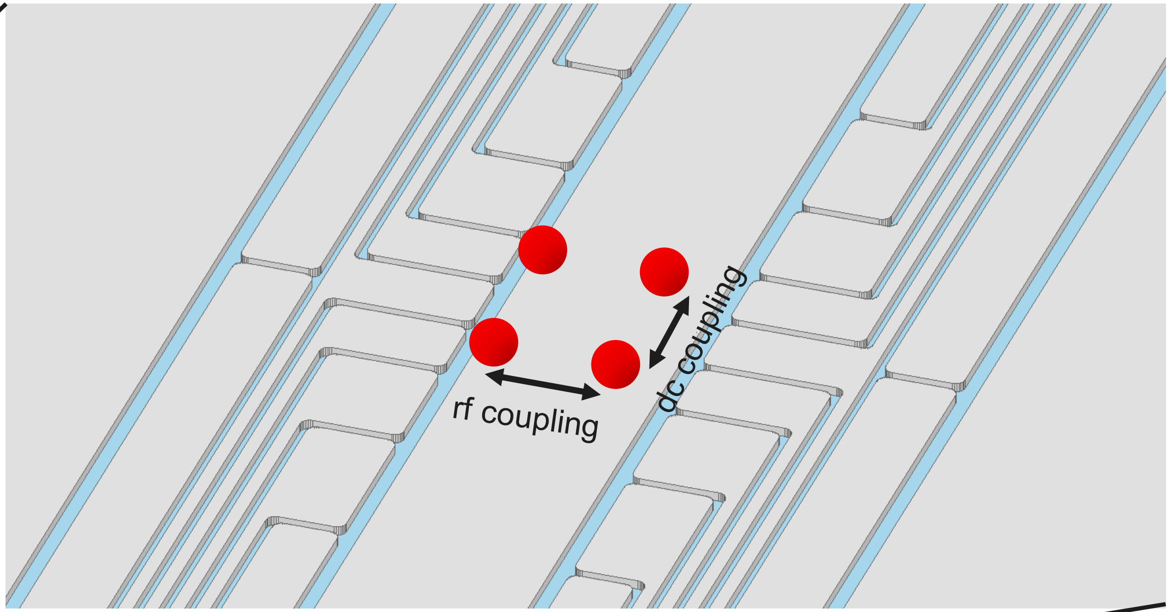
– Radial and axial coupling on one trap

– Smallest version: 4 ions in 4 wells

– Rf electrodes: 2S trap

– New set of dc electrodes for
  axial double-well potential





$2S^2$ trap - design

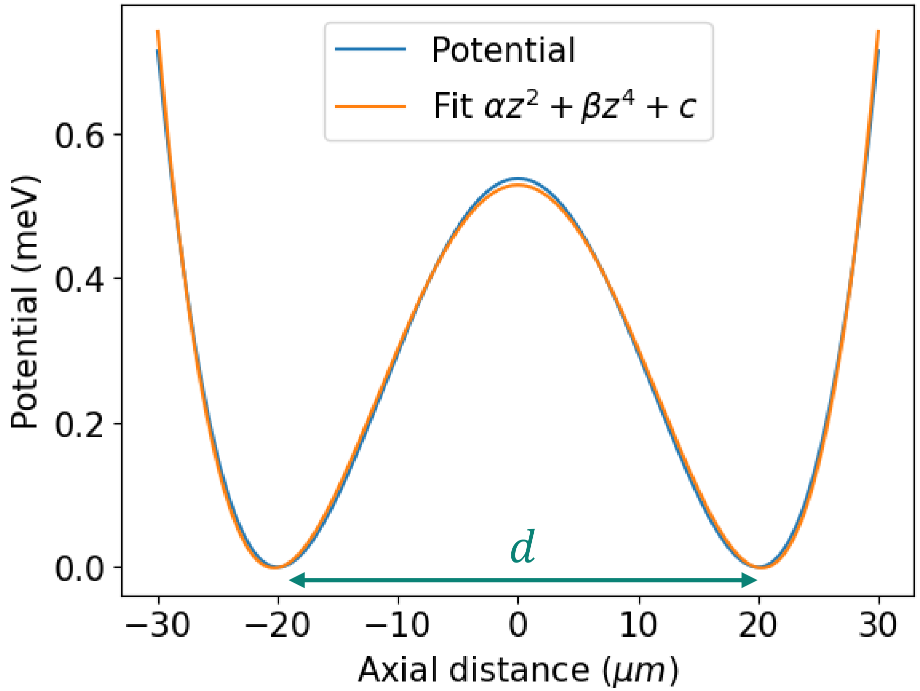
- Design: Choose dc electrode layout and electrode sizes
- Goal: minimize shim voltages @ $d_{ion} = 40\ \mu m$
- Axial double-well (symmetric):

Well-to-well distance

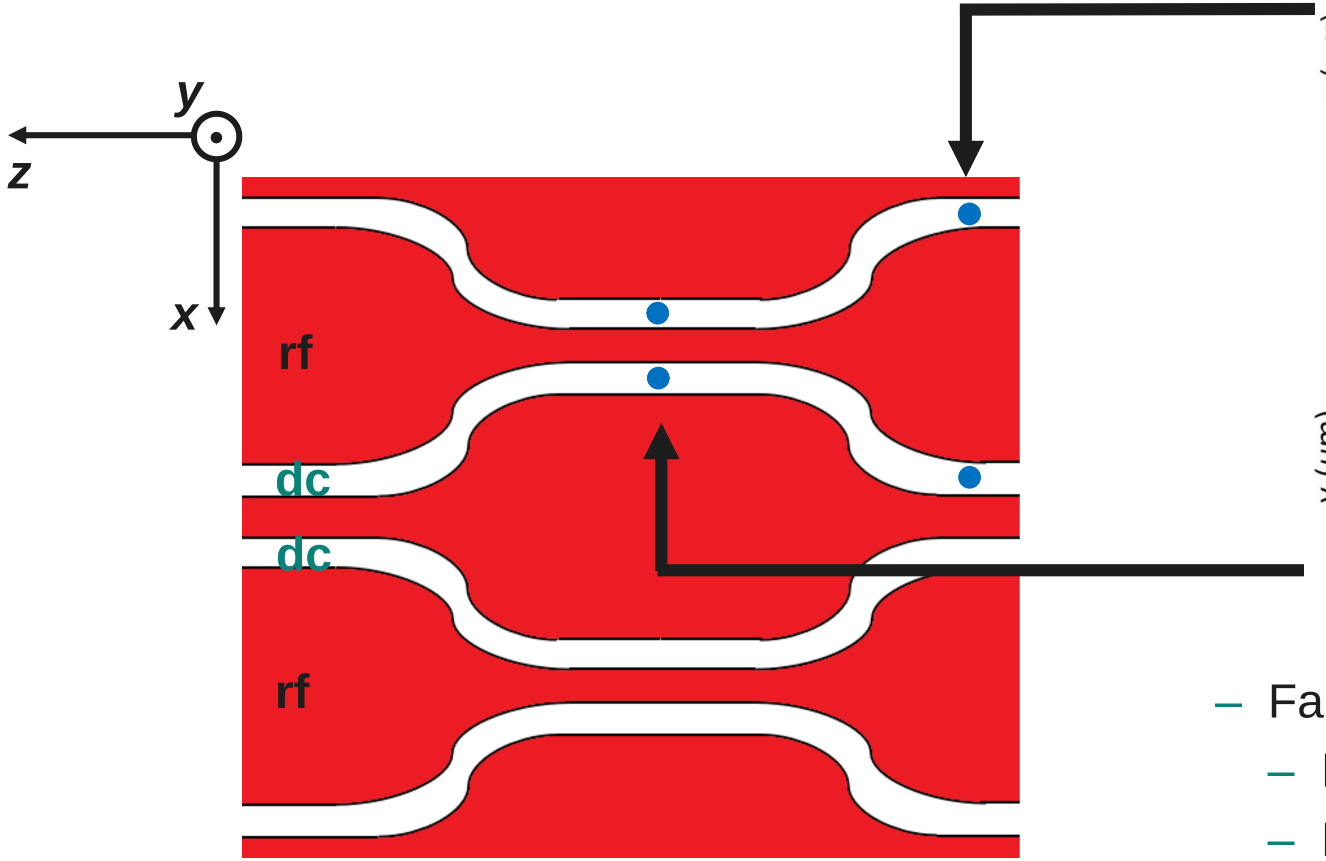
$$\varphi(z) = -\alpha z^2 + \beta z^4 + h = \frac{1}{32} m\omega_0^2 d^2 + \frac{m\omega_0^2}{2d^2}\left(z^4 - d^2 \frac{z^2}{2}\right)$$

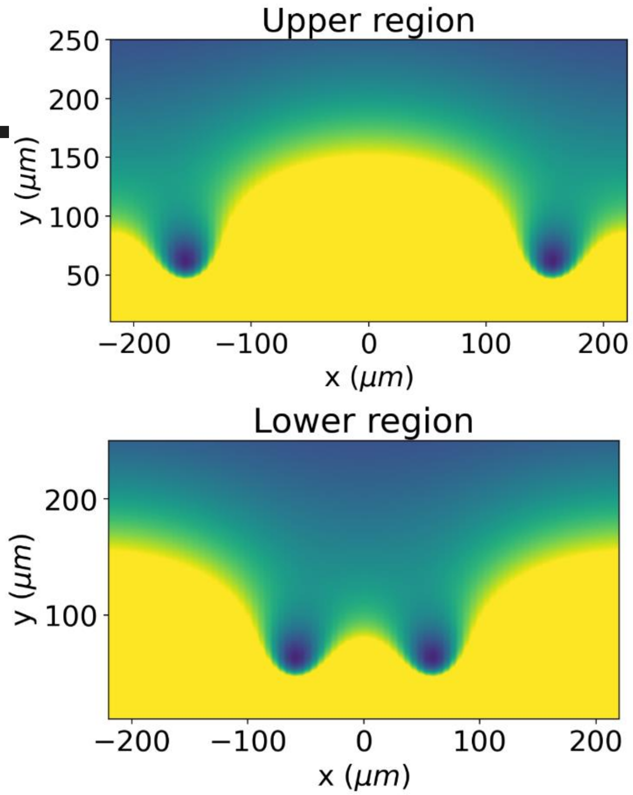
axial frequency

- Axial vs radial double-well
- Fabrication: single metal-layer on Fused Silica



Outlook: Meander trap





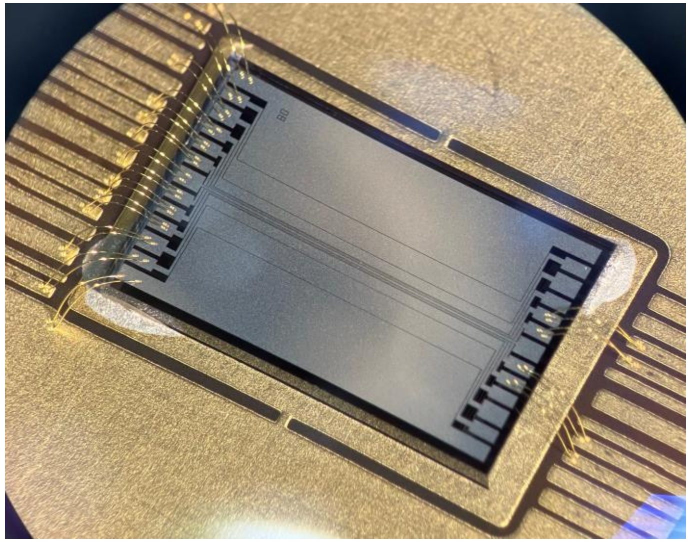
- Ion trap chip with axial dc and radial shuttling
- „Meander zones“: tune radial distance via dc shuttling

- Fabrication:
  - Multi-layer stack (complex electrode layouts)
  - Dielectric substrate (heating rates)
- Simulation:
  - Analytic model (fast)
  - Check with FEM

Summary

– Double-well coupling on dedicated industrially fabricated ion trap chips

– Scaling: Quantum Spring Array (QSA)



– Posters:
– Entanglement on the 2S trap: Marco Valentini
– Rydberg chip traps: Simon Schey
– Optical integration into glass traps: Jakob Wahl
– 3D ion traps: Max Glantschnig

– Paper:
M. Valentini, M. van Mourik, F. Butt, J. Wahl, M. Dietl, M. Pfeifer, F. Anmasser, Y. Colombe, C. Rössler, P. Holz, R. Blatt, M. Müller, T. Monz, P. Schindler: *Demonstration of two-dimensional connectivity for a scalable error-corrected ion-trap quantum processor architecture*, arXiv:2406.02406 (2024)

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