# Wiring up ion traps for quantum information

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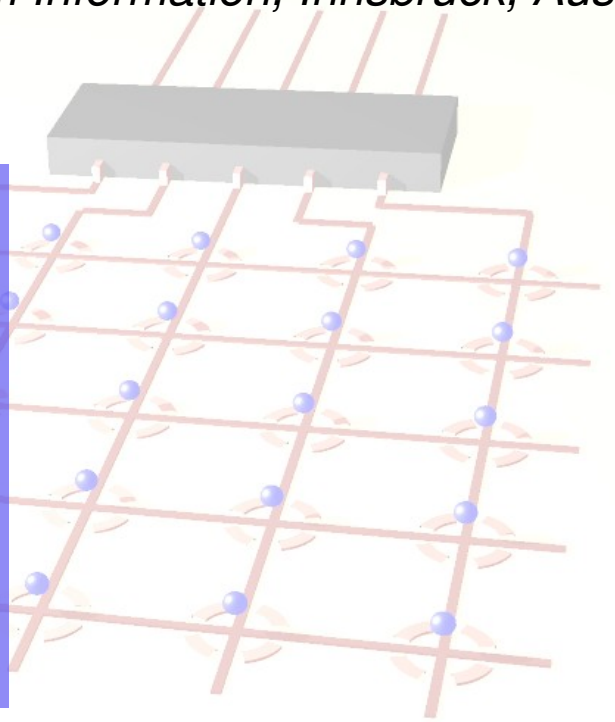


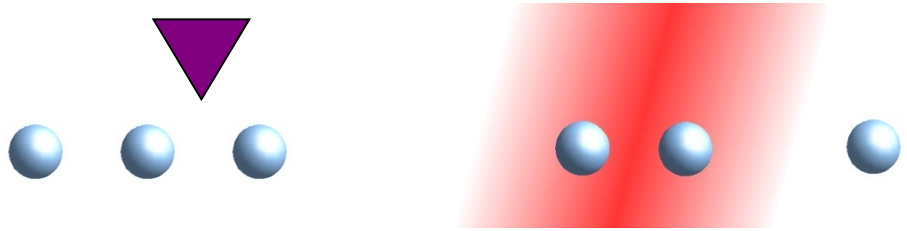
- Motivation
- Ion-wire interaction
- Characterization of the trap
- Influence of the wire
- Summary

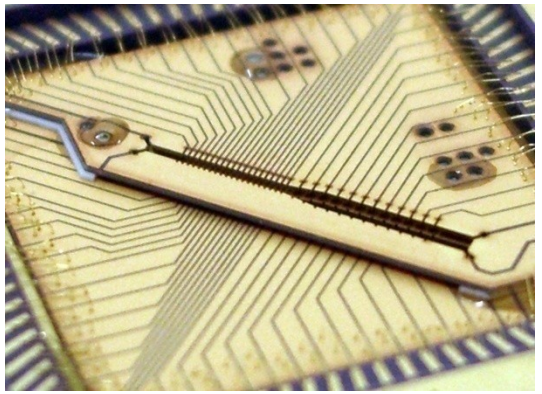
FWF bm:bwk

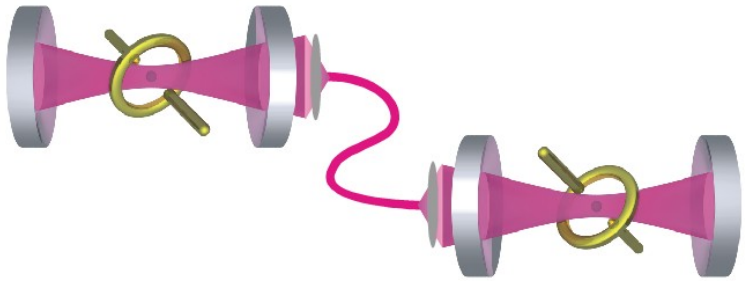
Tel Aviv, 4th May 2009

# Scaling of ion-trap quantum computers

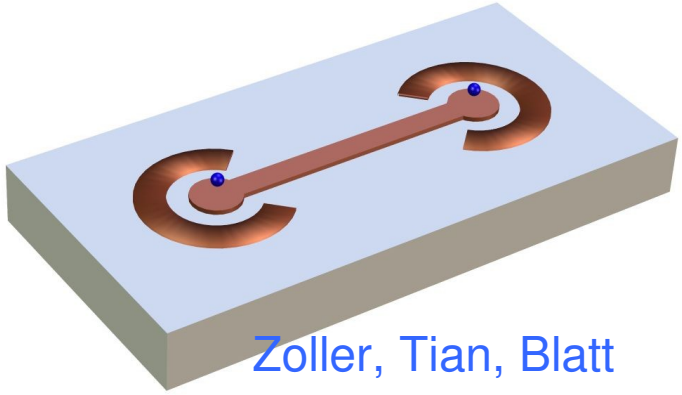
Kielpinski, Monroe, Wineland





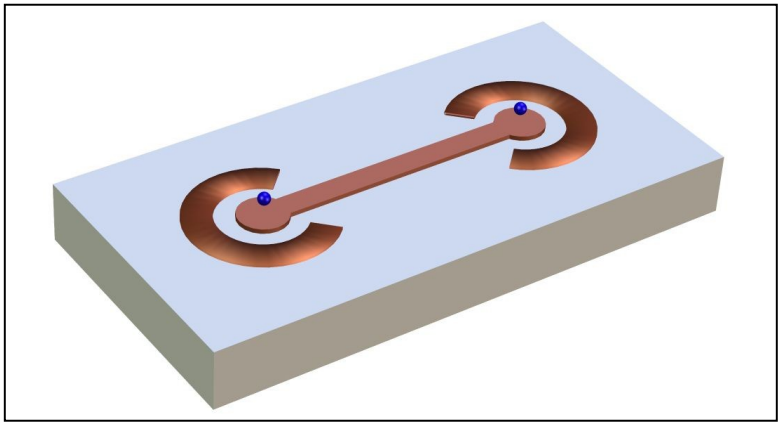


Cirac, Zoller, Kimble, Mabuchi



Zoller, Tian, Blatt

# Scaling of ion-trap quantum computers

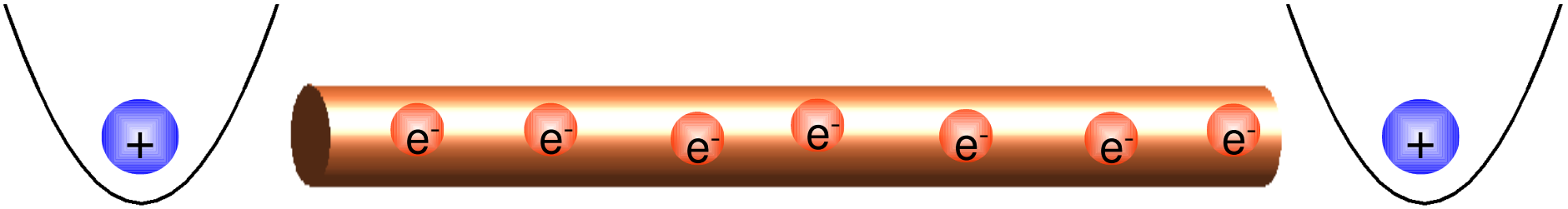


# Wiring up trapped ions

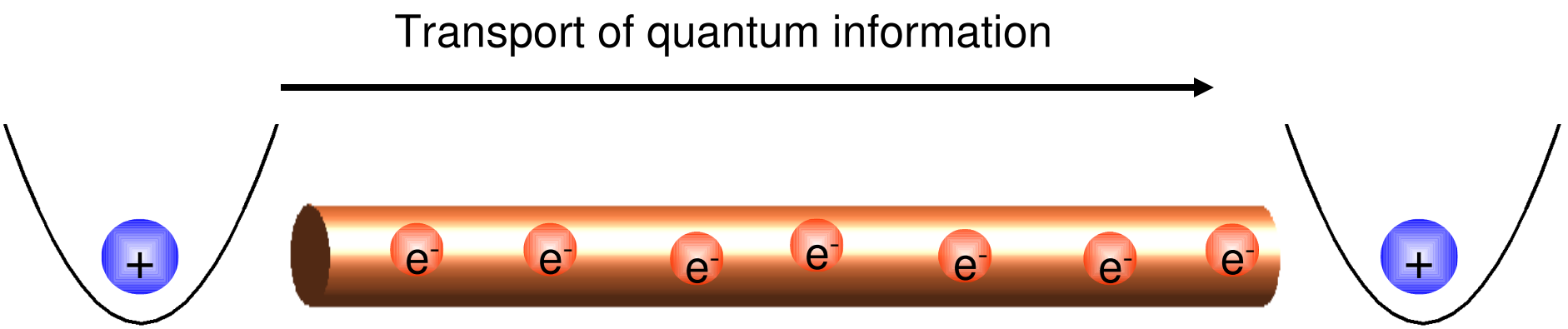
Two trapped ions …

# Wiring up trapped ions

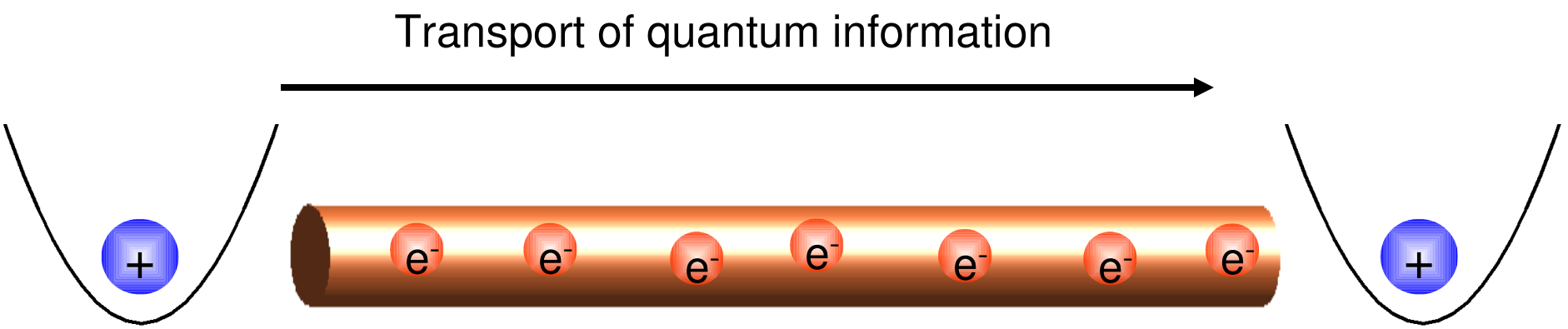
Two trapped ions + a wire



# Wiring up trapped ions



# Wiring up trapped ions




No trace of the quantum information should remain in the wire

➡ ~~super conducting~~ wire

# Physics with this set-up

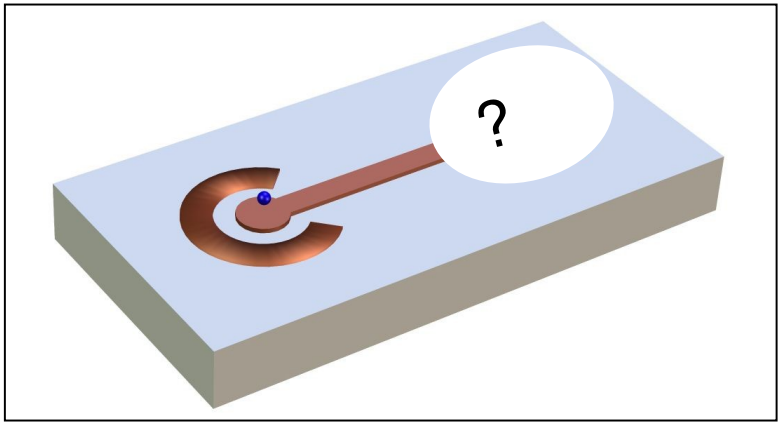
**Physics:**

- Decoherence in charge transport
- Wire mediated laser cooling to a few μK
- Cooling of LC resonators

Heinzen and Wineland, PRA PRA **47**, 2977 (1990).

**Technology:**

- Scalable quantum computing with trapped ions/electrons
- Hybrid quantum computing
- Quantum detectors



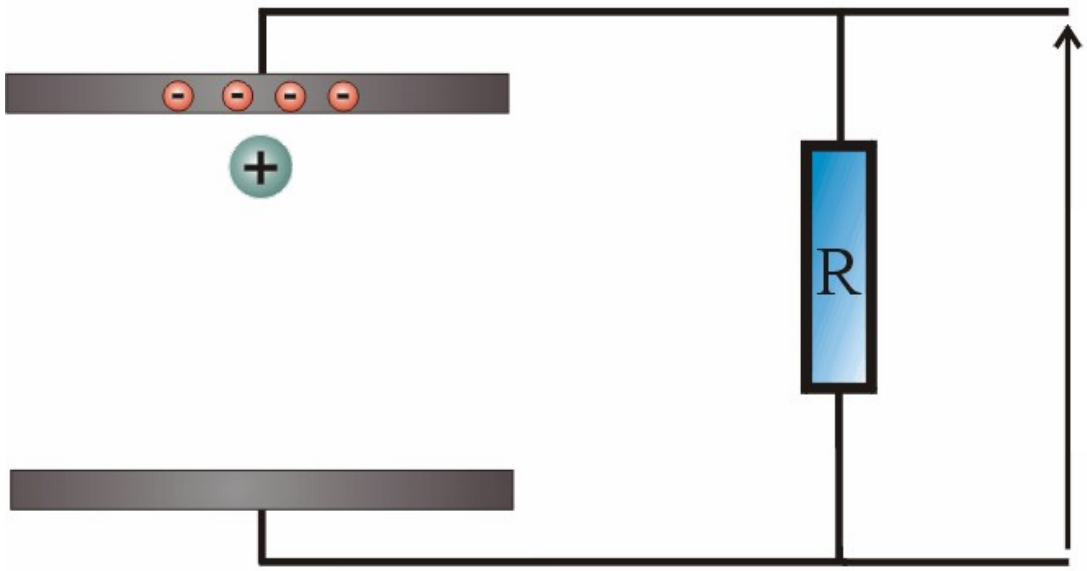
Quantum control

Ion-wire interaction

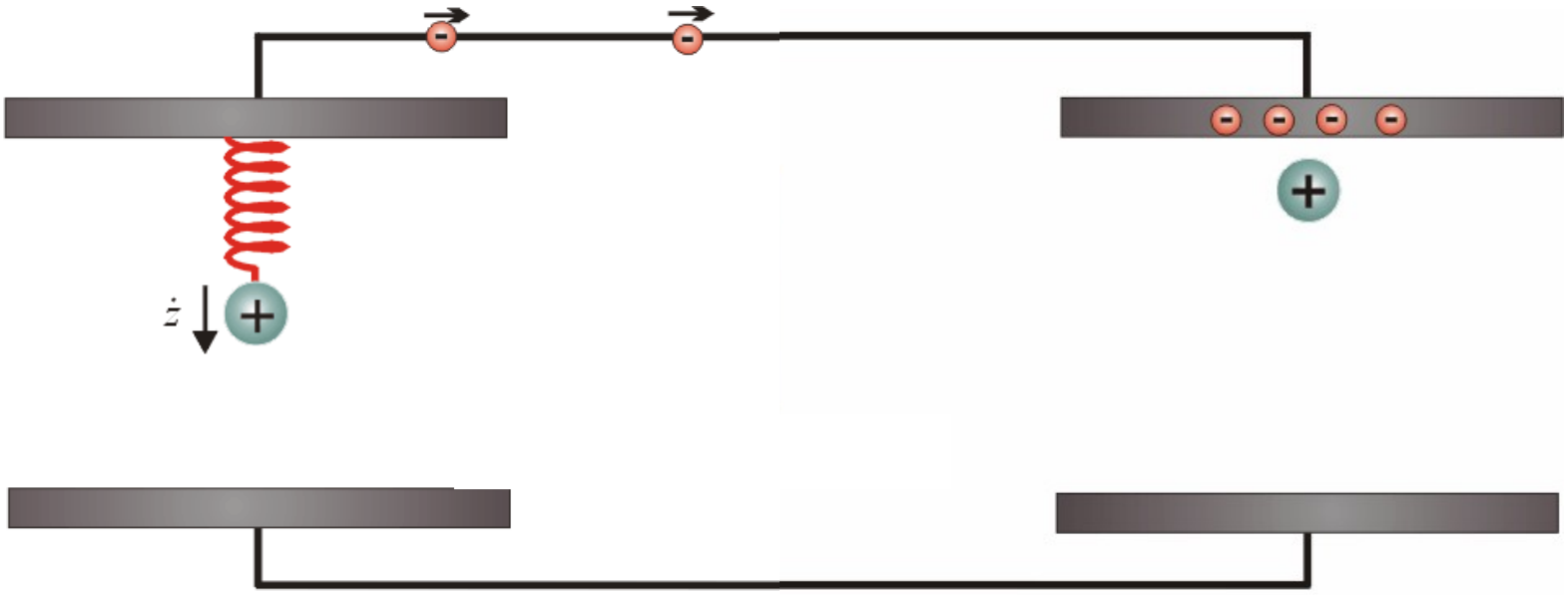
Experiments

Summary

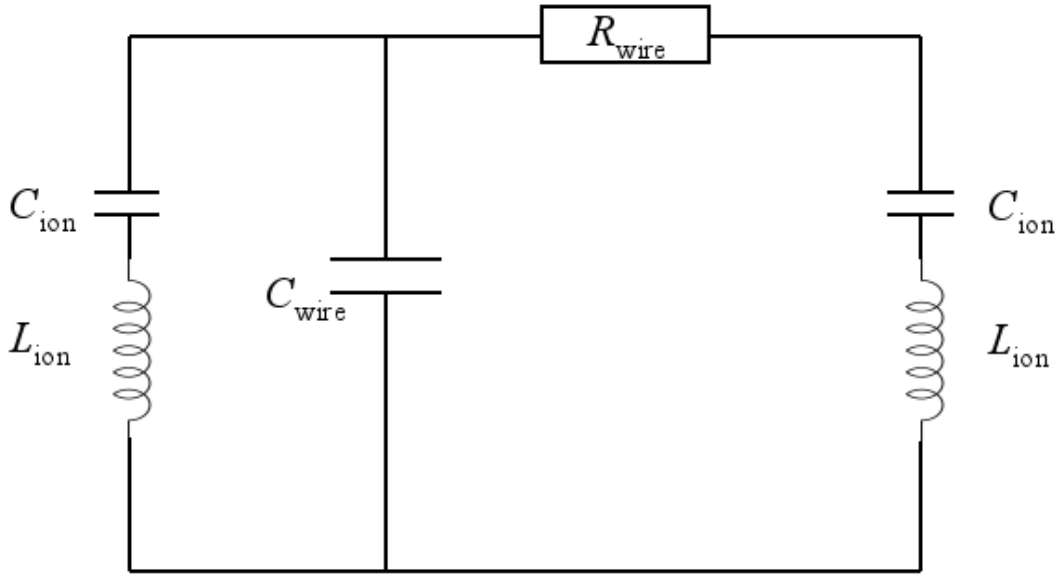
# Ion-resistor interaction



# Ion-resistor interaction



# Coupling



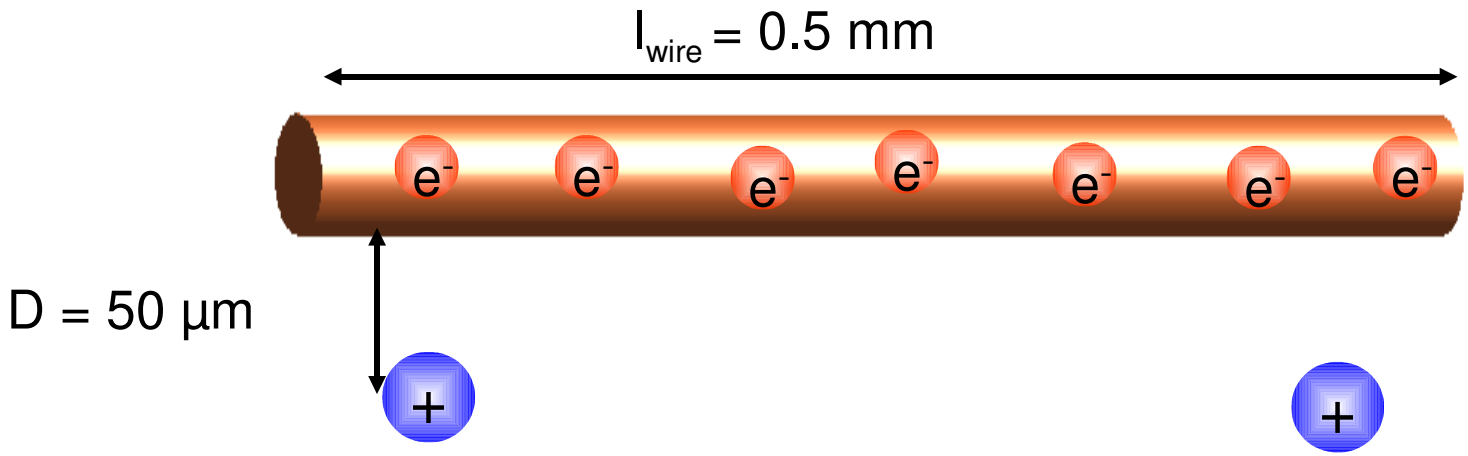

with $$I = \frac{q}{D}\dot{x}, \quad L_{\text{ion}} = \frac{mD^2}{q^2}, \quad C_{\text{ion}} = \frac{1}{\omega^2 L_{\text{ion}}}$$

Energy exchange rate: $$\frac{1}{T} = \frac{1}{2\pi}\frac{q^2}{mD^2}\frac{1}{\omega}\frac{1}{C_{\text{wire}}}$$


D.J. Wineland and H.G. Dehmelt, J. Appl. Phys **46**, 919 (1975).

D.J. Heinzen and D.J. Wineland, PRA **47**, 2977 (1990).

# Coupling




Projected numbers:

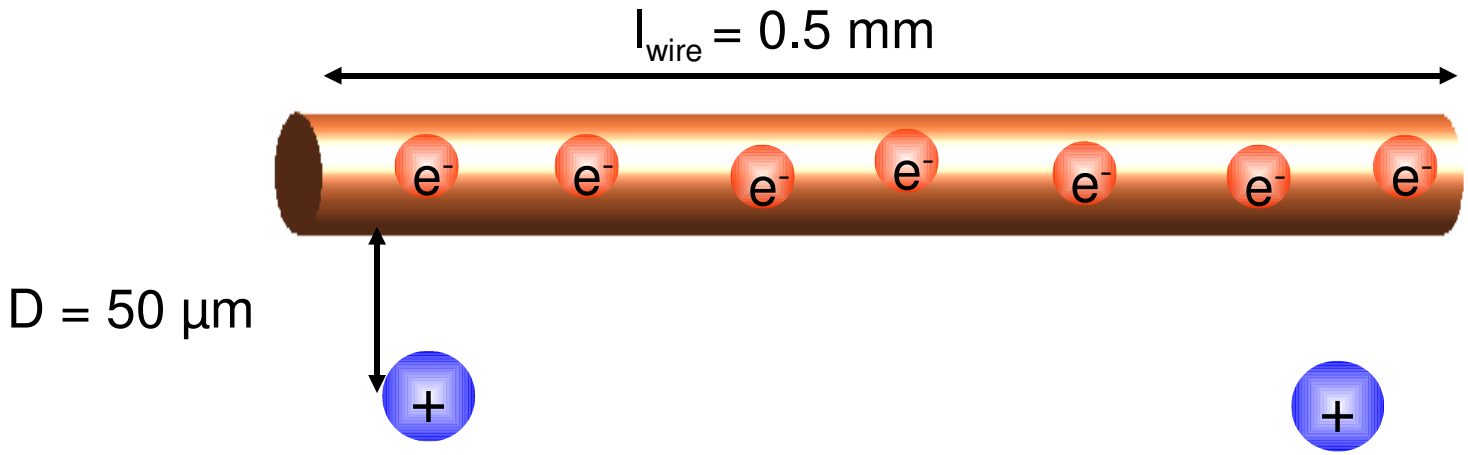
$D_{eff}$ = 3.6 X 50 μm

ω =2π X 500 kHz

$C_{wire}$ = 6 fF ($l_{wire}$ = 0.5mm)

γ = 2π X 100 Hz

# Coupling




Current numbers:

$D_{eff}$ = 3.6 X 300 μm

$\omega = 2\pi$ X 500 kHz

$C_{wire}$ = 120 fF ($l_{wire}$ = 1cm)

$\gamma$ would be $2\pi$ X 0.14 Hz

Projected numbers:

$D_{eff}$ = 3.6 X 50 μm

$\omega = 2\pi$ X 500 kHz

$C_{wire}$ = 6 fF ($l_{wire}$ = 0.5mm)

$\gamma = 2\pi$ X 100 Hz

# Decoherence

**Dissipation in the wire**

Trap parameters: $\omega = 2\pi \cdot 500\ kHz$, $D = 3.6 \cdot 50\ \mu m$, $R = 0.1\ \Omega$

Induced current: $$I = \frac{q}{D}\dot{x} = \frac{q}{D}\sqrt{\frac{\hbar\omega}{m}} \approx 10^{-16}\ A$$

Dissipation rate for motional quantum: $$\gamma = \frac{I^2 R}{\hbar\omega} \approx 10^{-6}\ \frac{1}{s}$$

But what about Johnson noise?

# Decoherence

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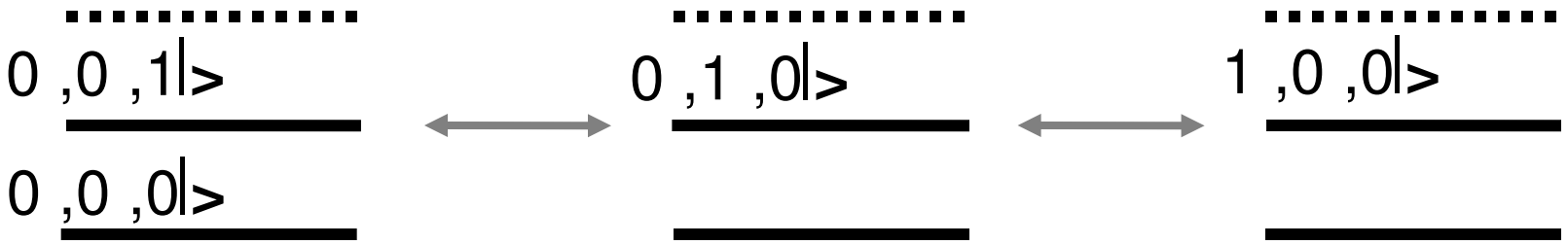
**Johnson noise heating**

Heating rate : $$\gamma_J = \frac{P_J}{\hbar\omega} = \frac{k_B T\gamma}{\hbar\omega} \approx 14\frac{1}{s}$$

Expected coupling over 0.5 mm: 2π X 100 1/s

# Decoherence

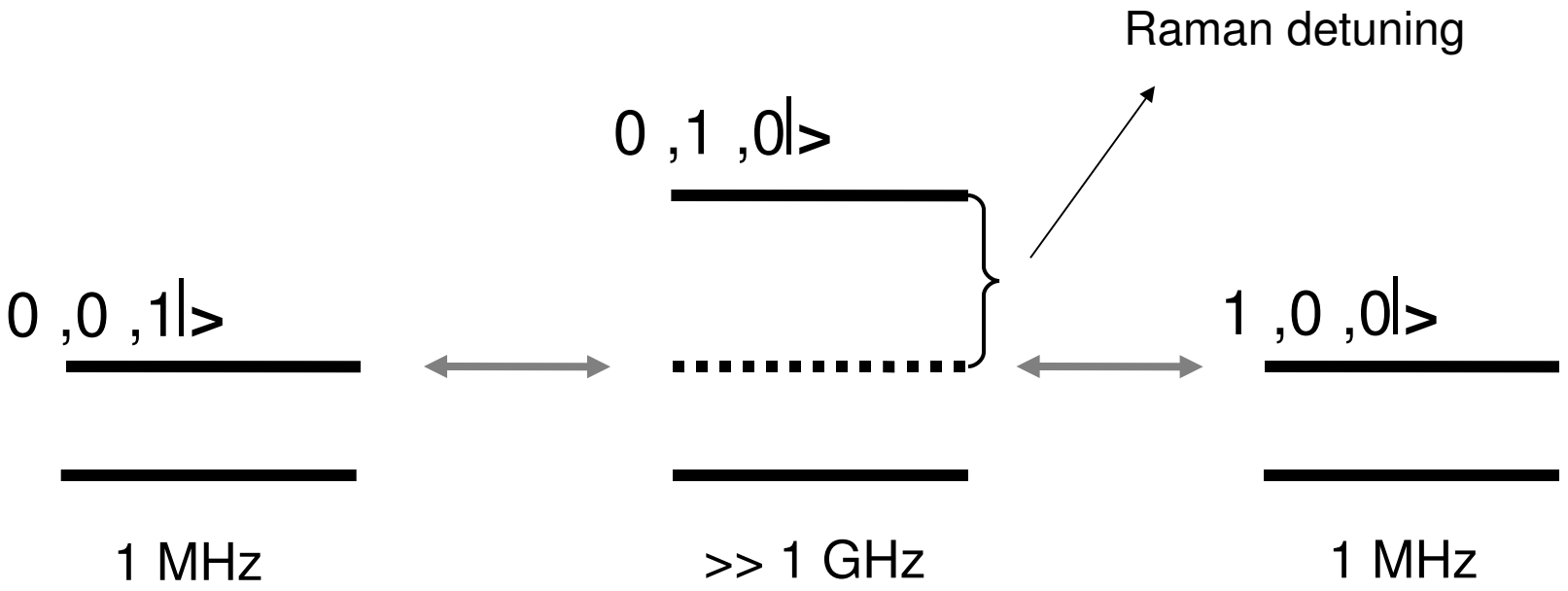
Three coupled harmonic oscillators:




$|\text{ion}_1, \text{wire}, \text{ion}_1\rangle$

# Decoherence

Three coupled harmonic oscillators:



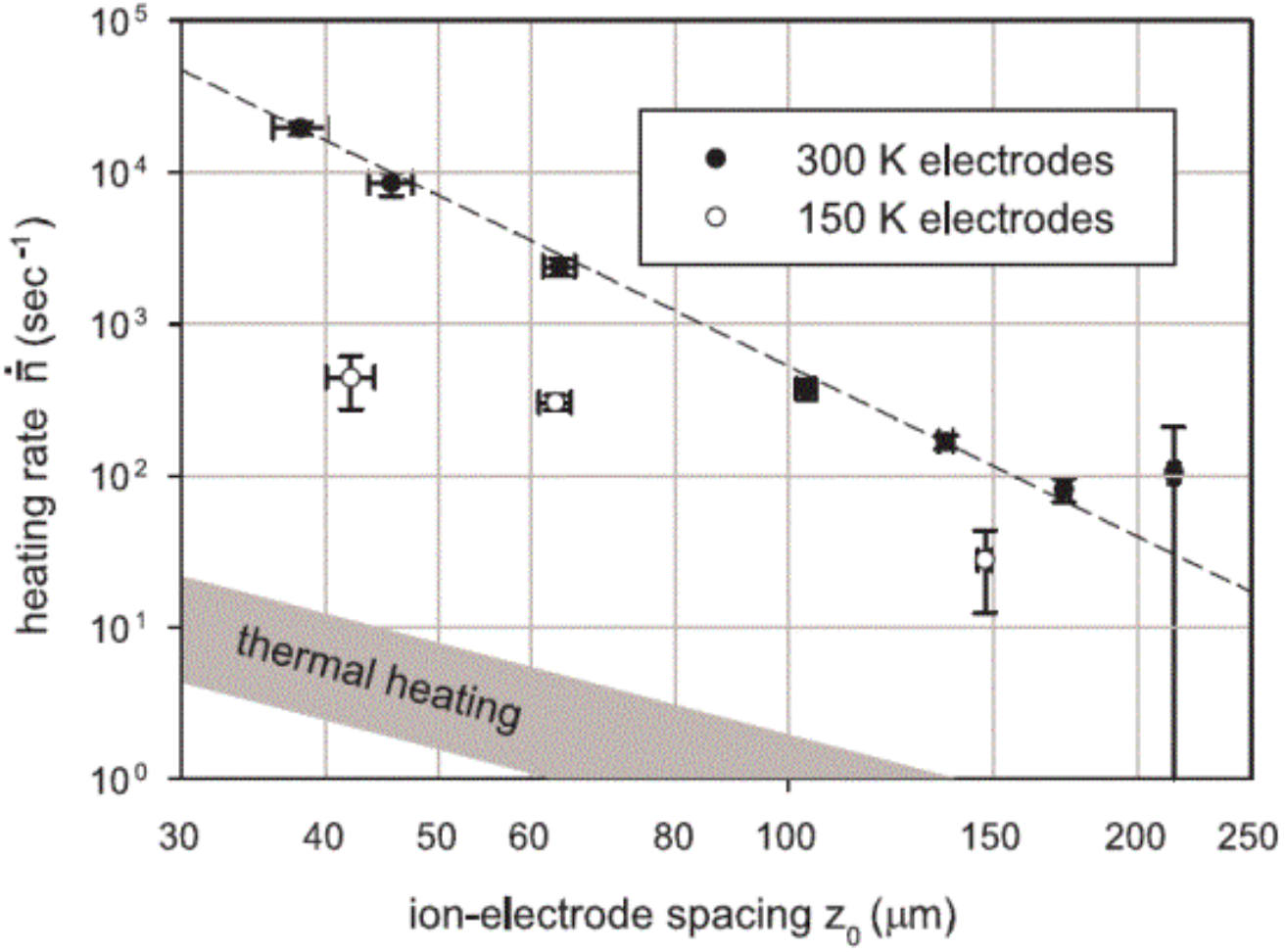

$|ion_1, wire, ion_1\rangle$

# Decoherence

Anything else ?

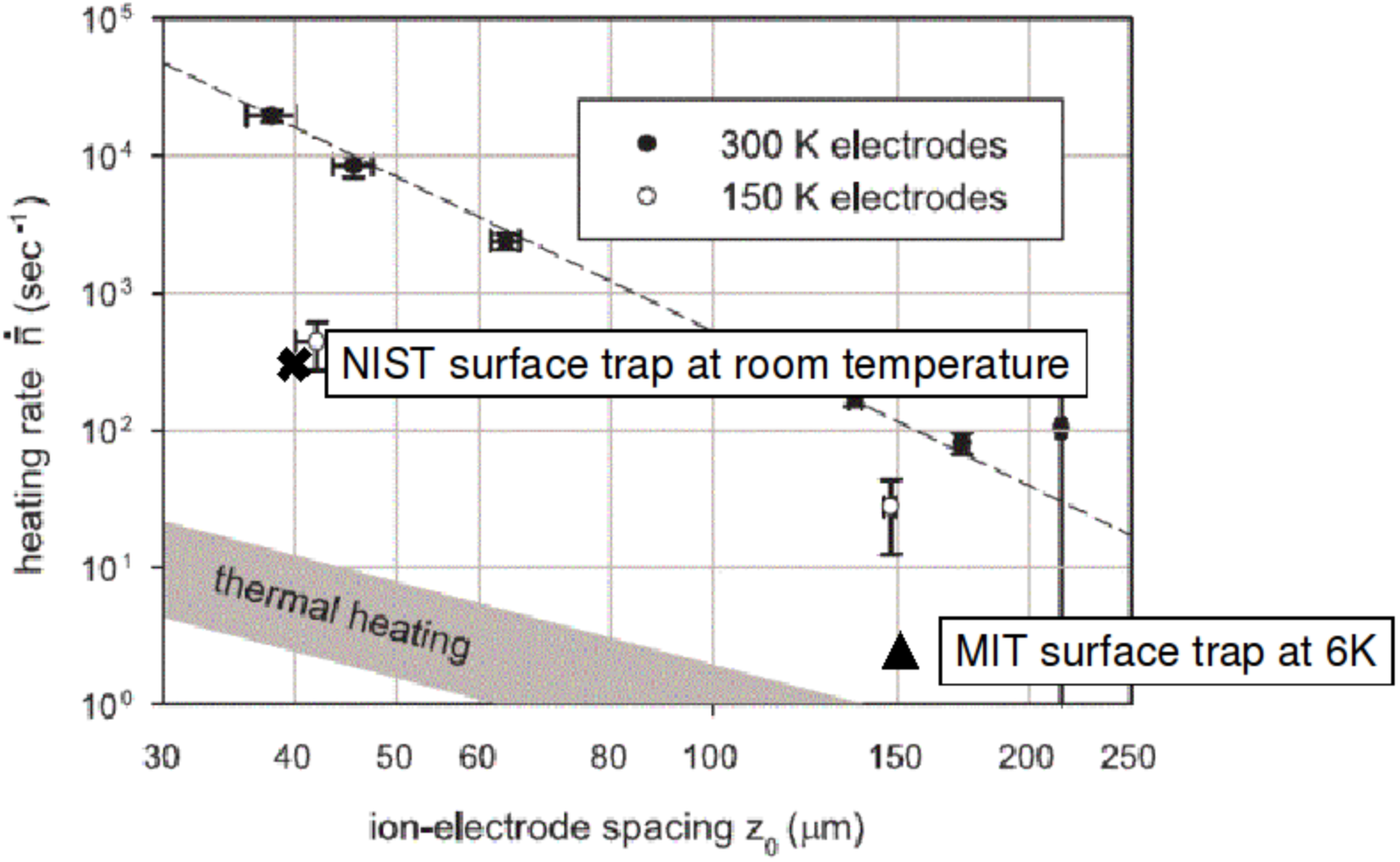
See: J.R. Zurita-Sánchez and C. Henkel, submitted to New J. Phys. (2008).

# Anomalous heating



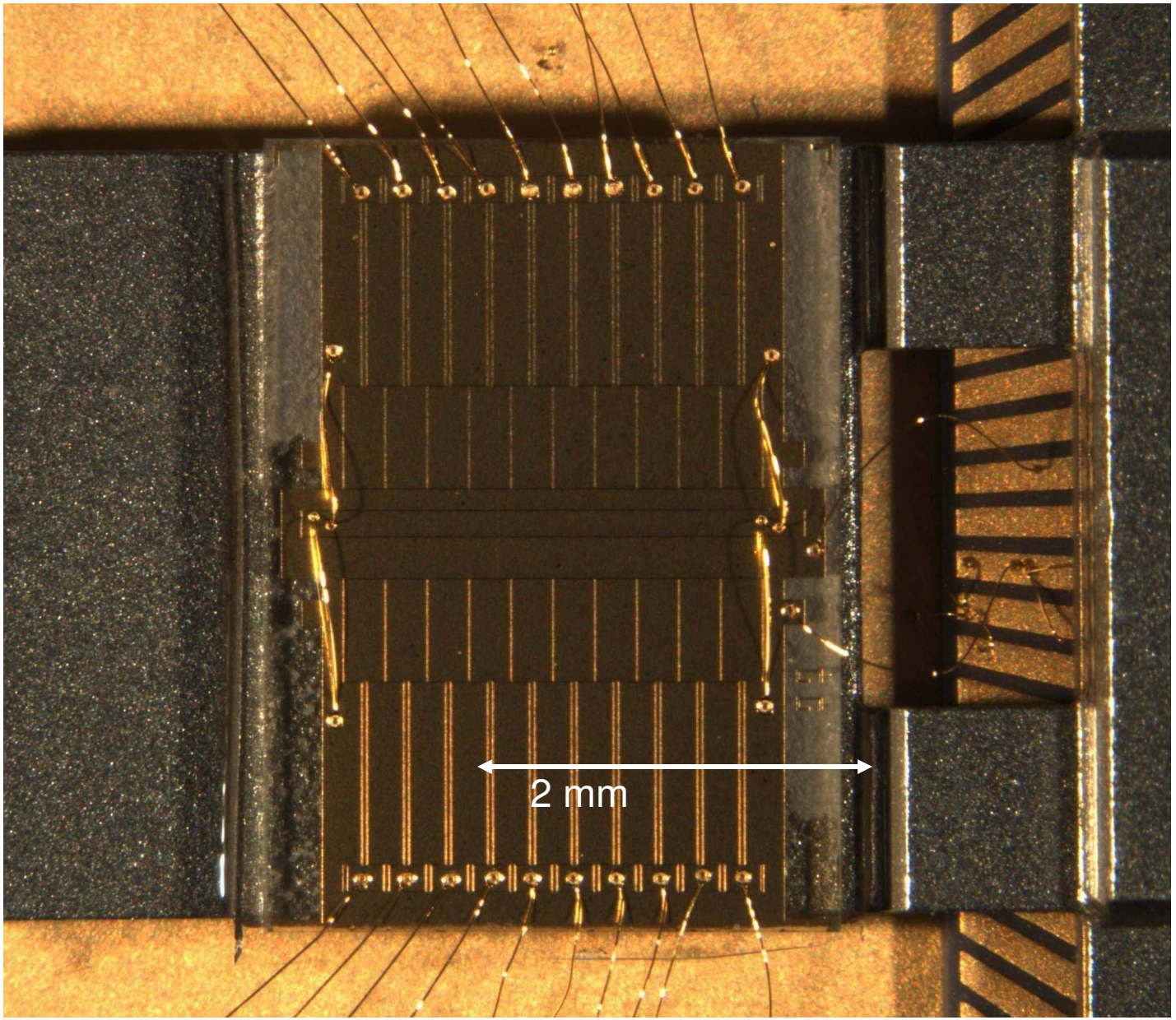

From: L. Deslauriers et al.,PRL 97, 103007 (2006).

# Anomalous heating



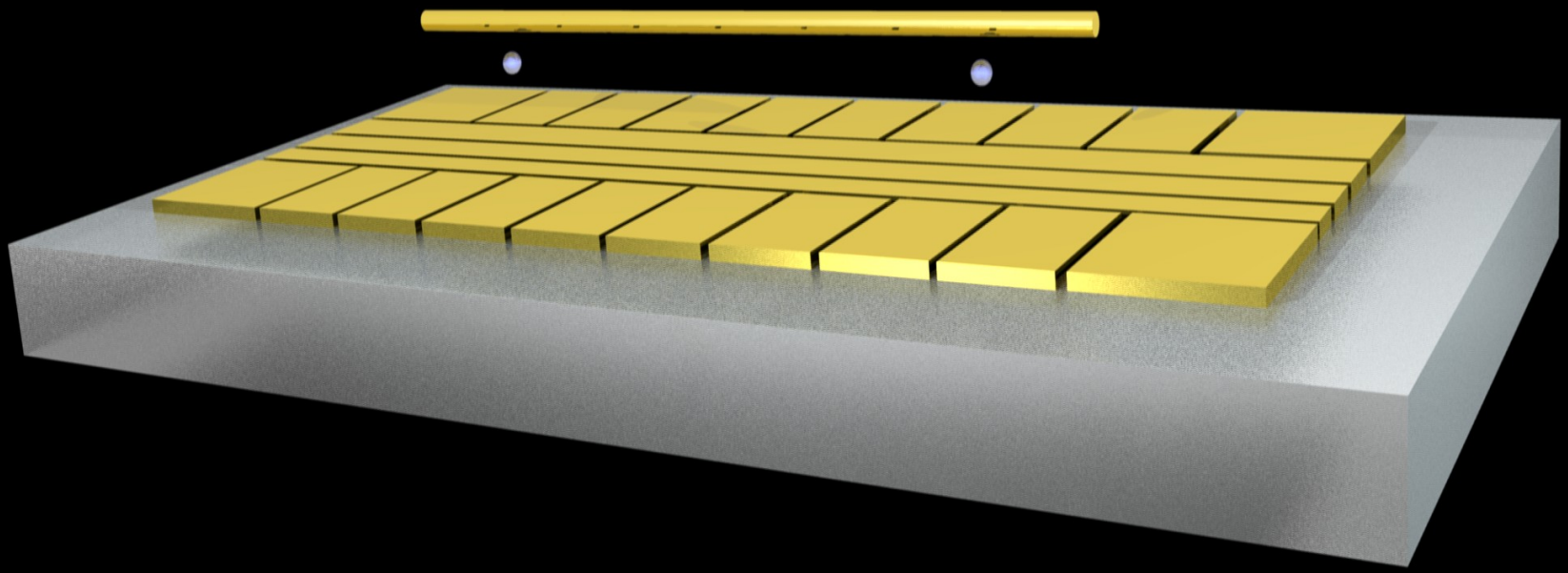

From: L. Deslauriers et al.,PRL 97, 103007 (2006).

# A surface trap

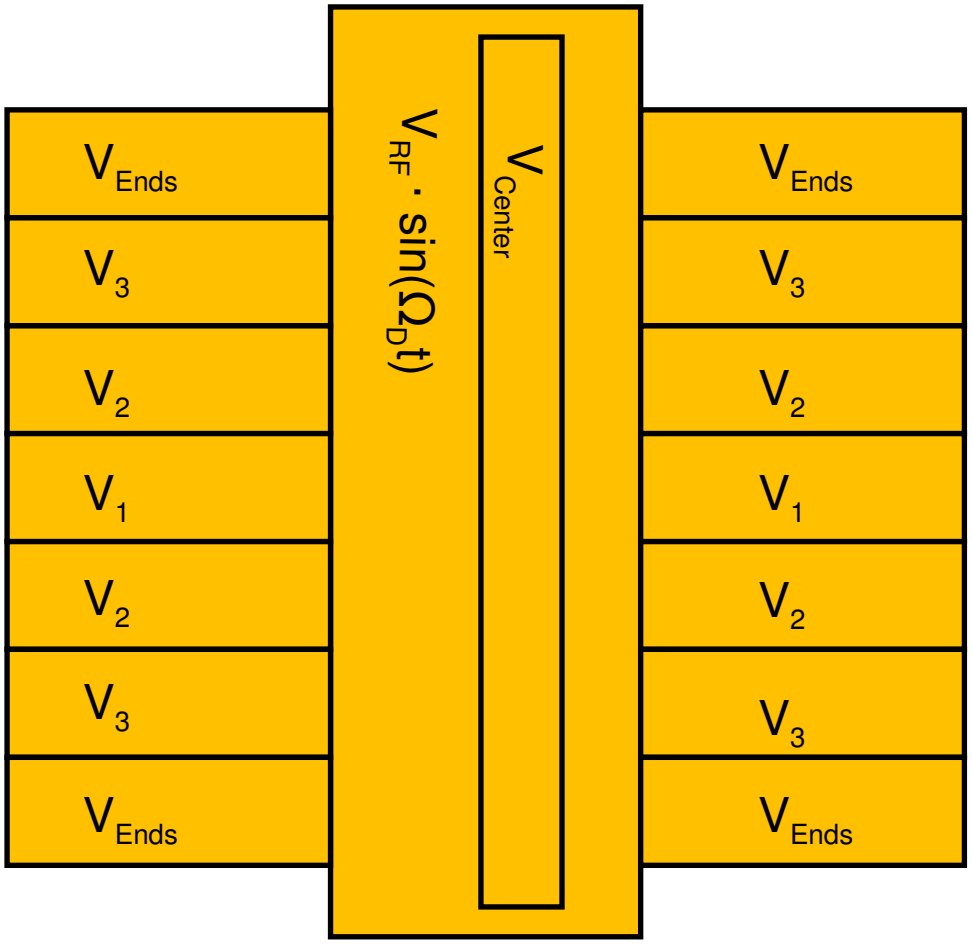



Nikos

# Experimental set-up



# Trap parameters




Trap parameters:

Ion height ≈ 220 μm

$\Omega_D = 2\pi \cdot 15$ MHz

$V_{RF} \approx 100$ V

$V_{DC} < 10$ V

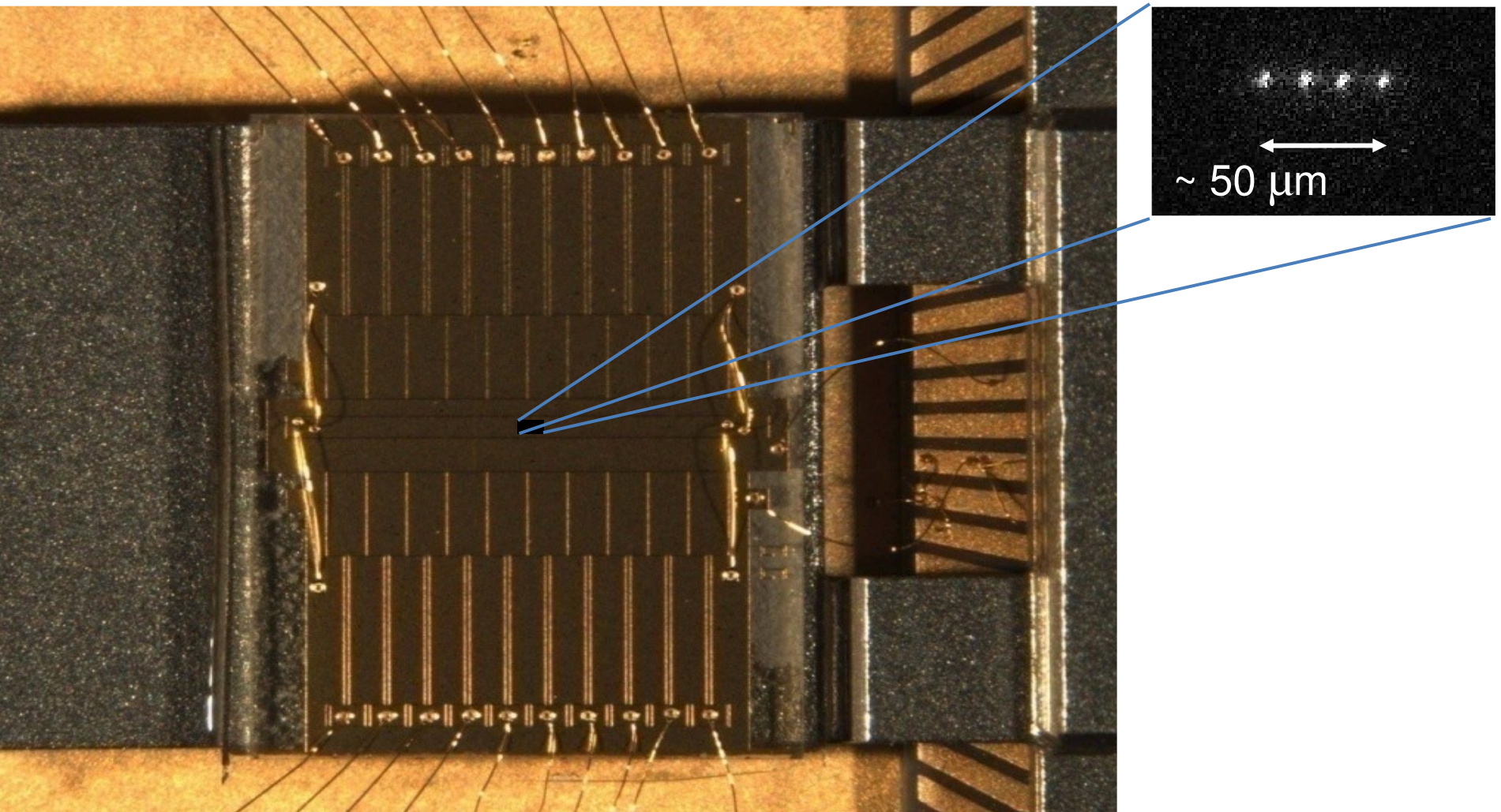
$\omega_H \approx 2\pi \cdot 1.3$ MHz

$\omega_V \approx 2\pi \cdot 1.5$ MHz

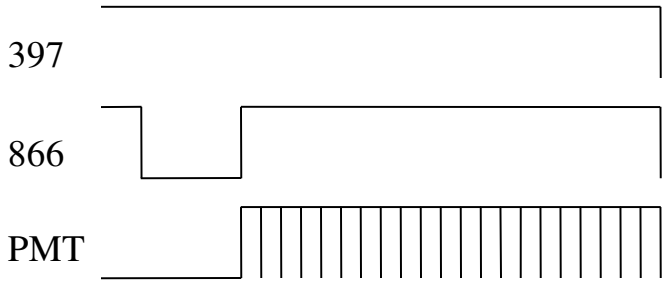
$\omega_A \approx 2\pi \cdot 300$ kHz

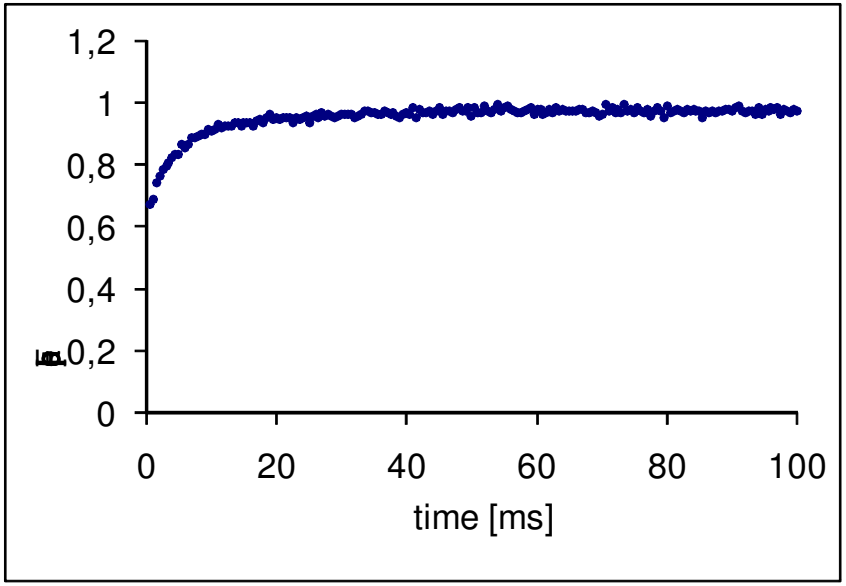
Tilt ≈ 20°

# Experimental set-up



# Heating rate measurement



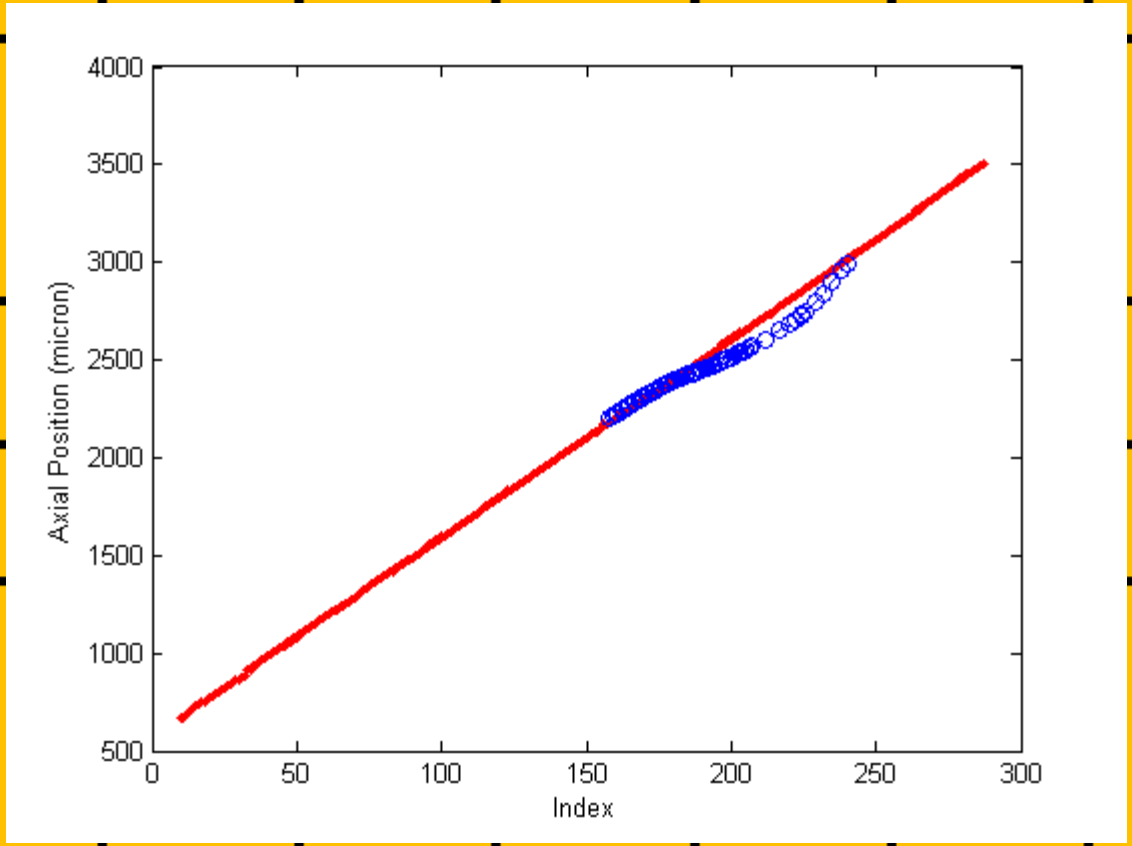



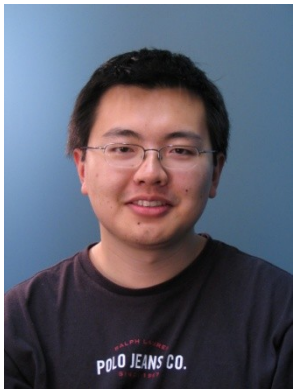

Heating rate determined from difference in fluorescence

Preliminary result: 5 Quanta/ms

J.H. Wesenberg et al, PRA **76**, 053416 (2007).

# Trap characterization

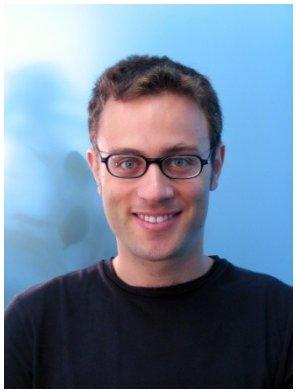




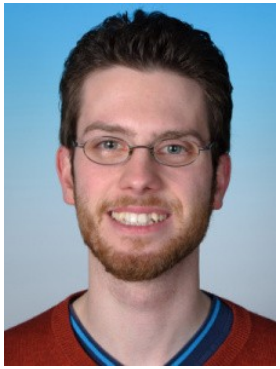

Tony

Rob

Sankar



Nikos

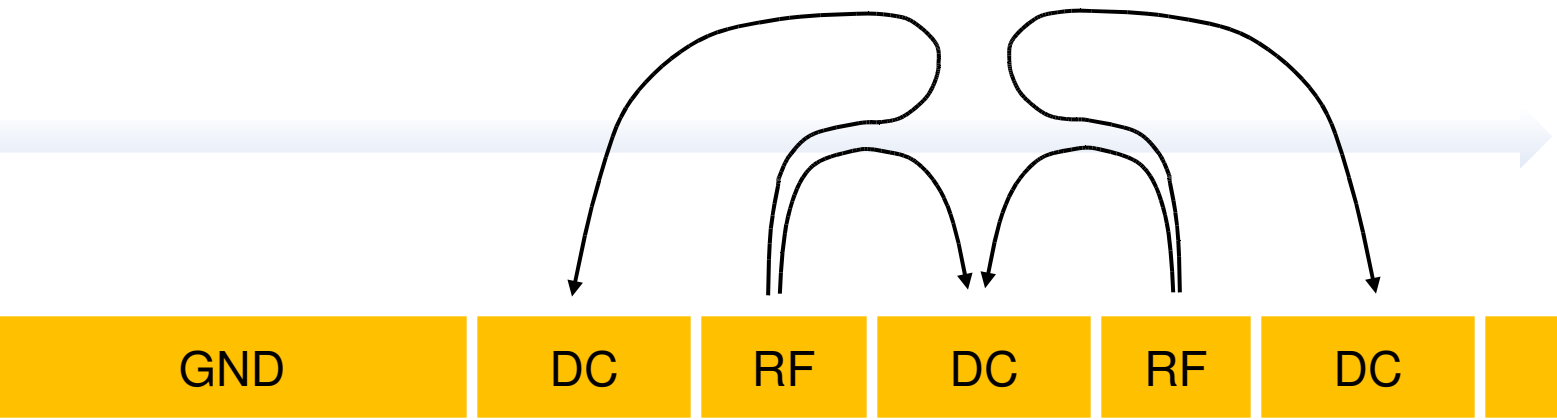


Sönke

\+ Andreas Wallraff, Peter Leek (Zürich)

Frank Ziesel, Uli Poschinger, Kilian Singer, Ferdinand Schmidt-Kaler (Ulm)

# Micromotion compensation



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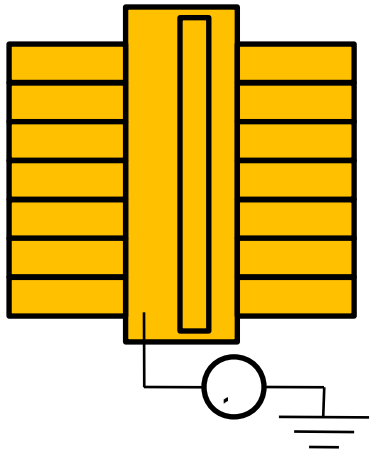
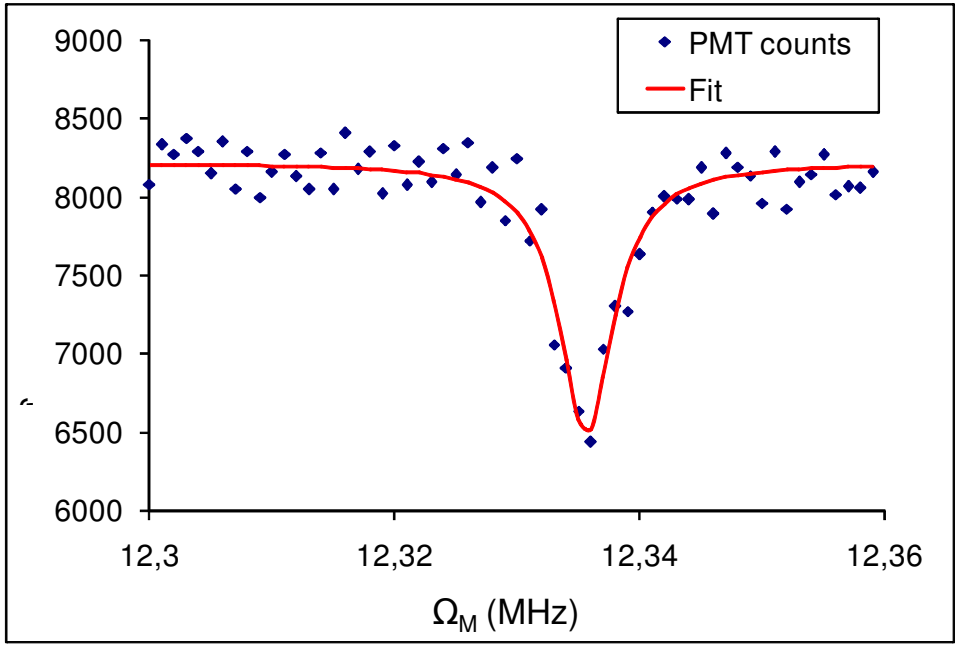
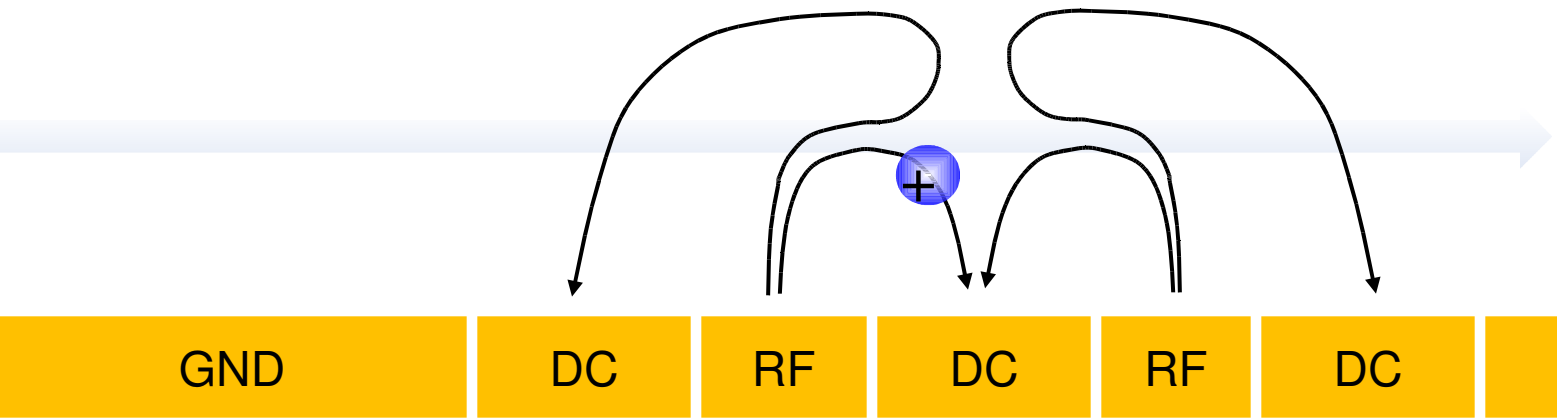





Drive a motional sideband (of the micromotion)

See also NIST

# Micromotion compensation




See also NIST

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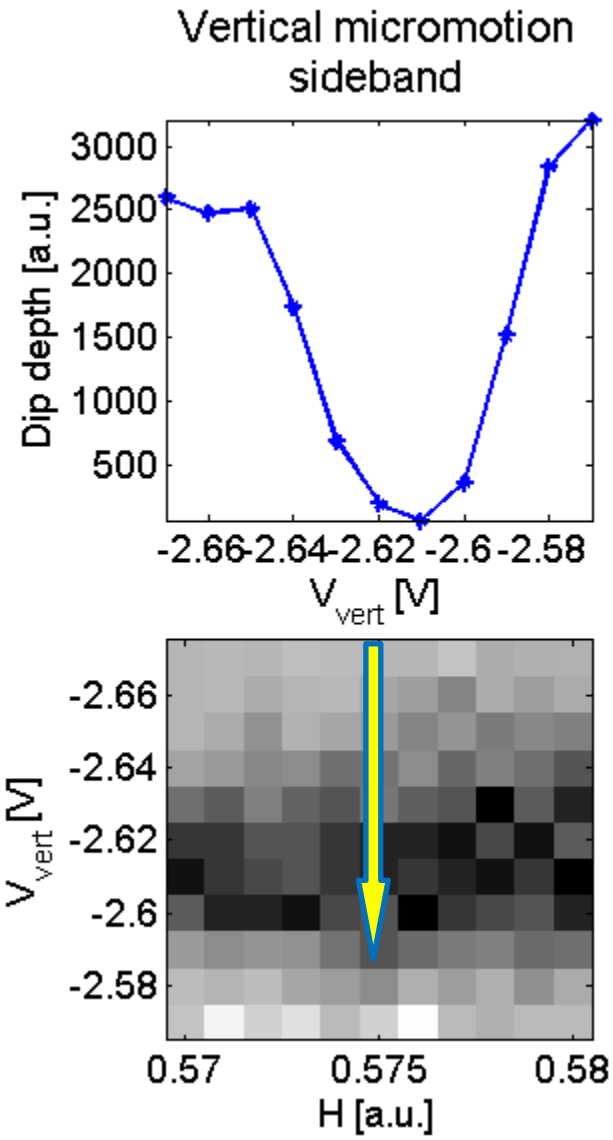



Compensated position:

$\Delta x_V$ = 300 nm

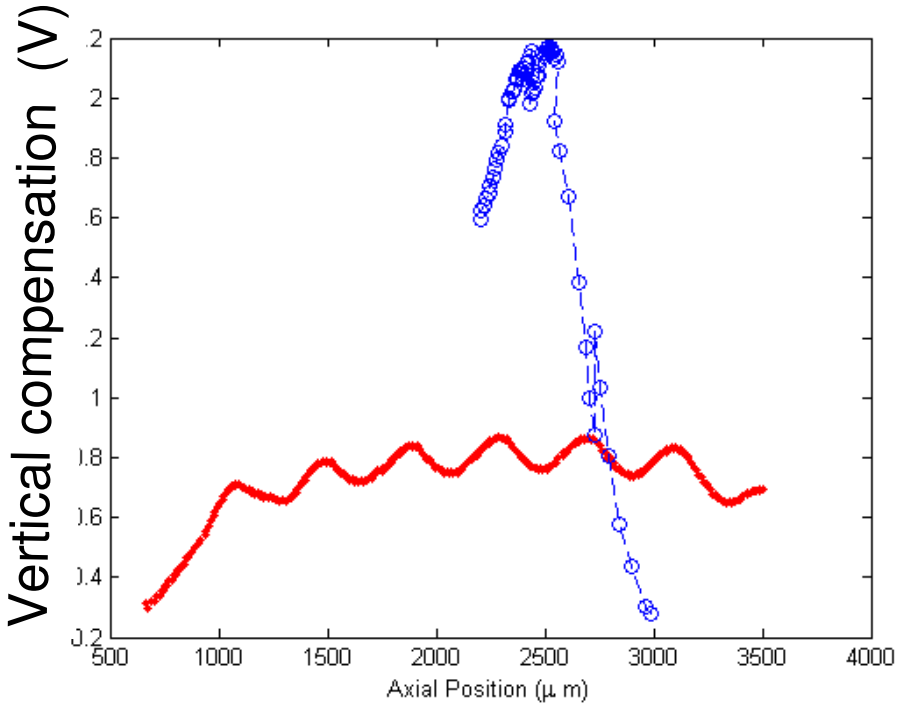
$A_{mm,v}$ = 38 nm

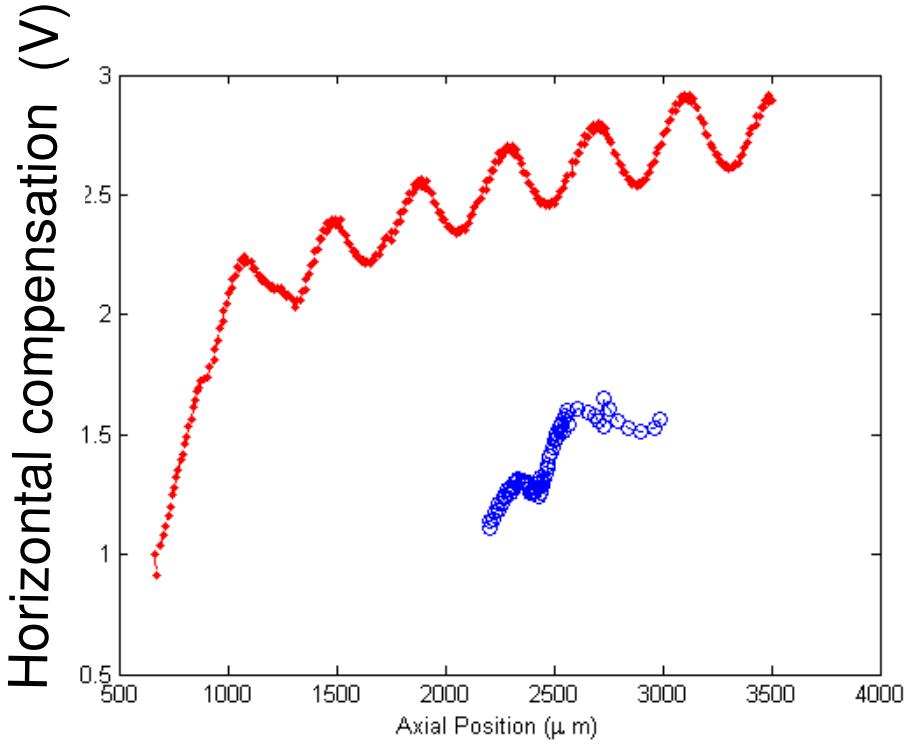
$\Delta x_H$ = 47 nm

$A_{mm,H}$ = 5.9 nm

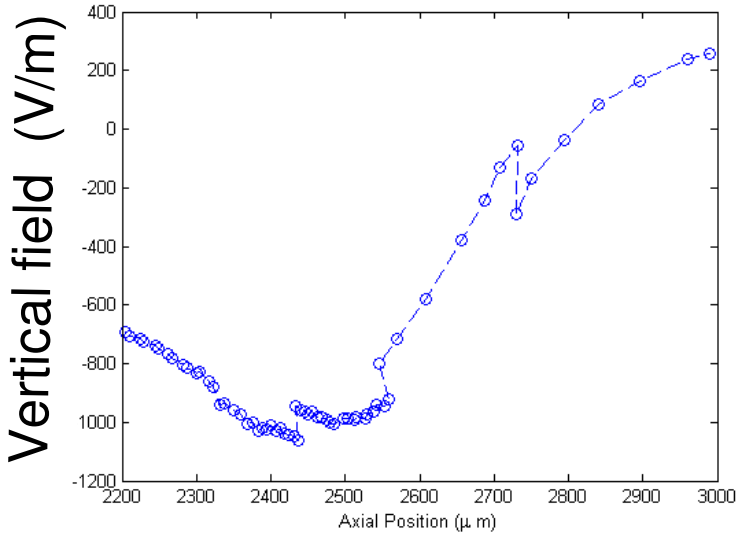
can be improved

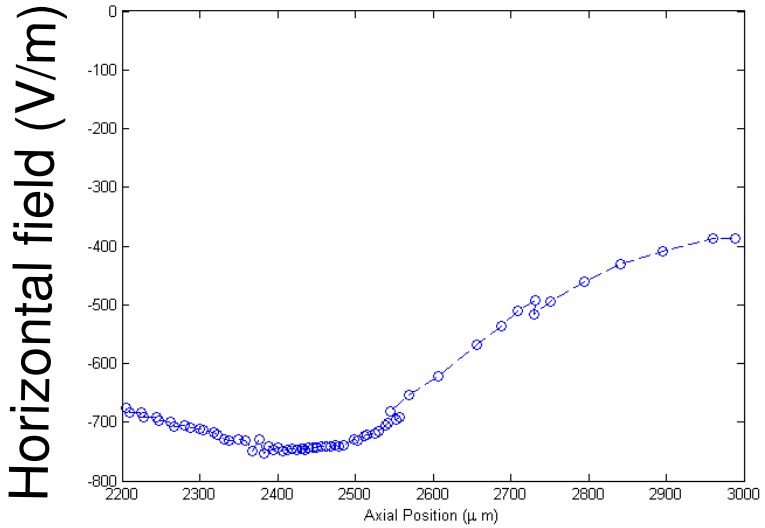
# Compensation

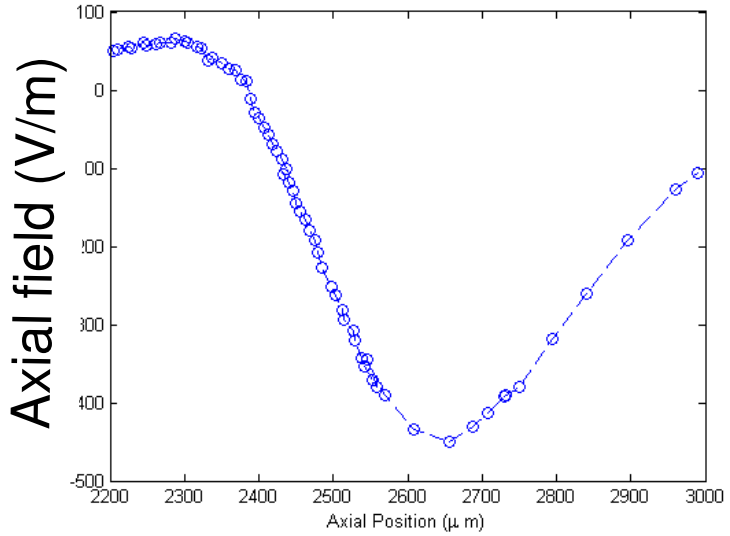


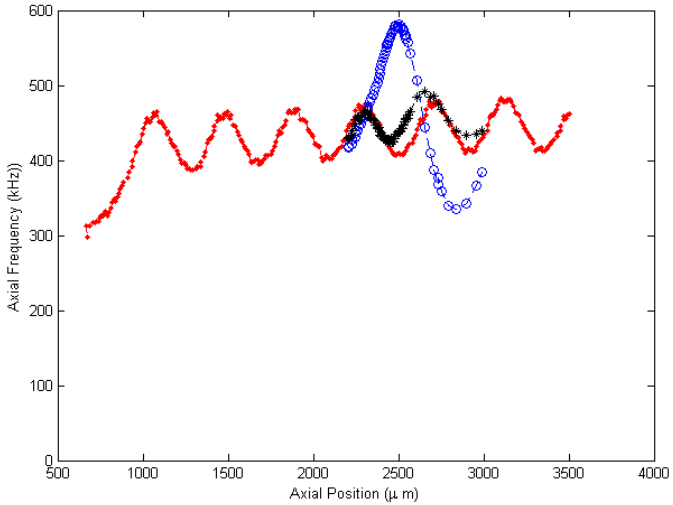
# Derived electric stay fields

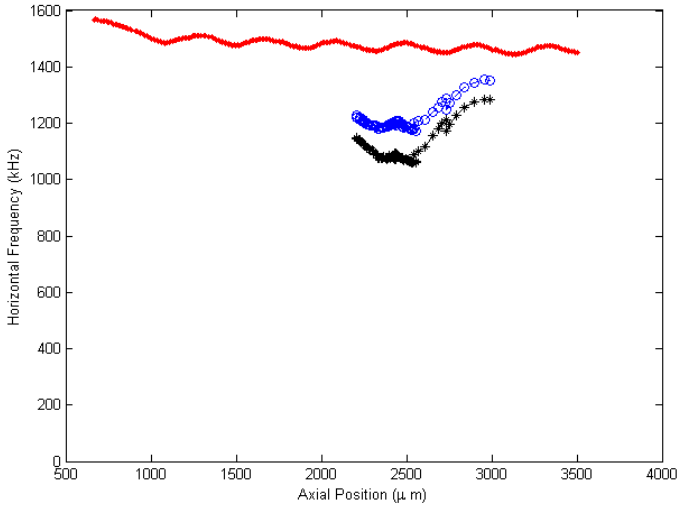


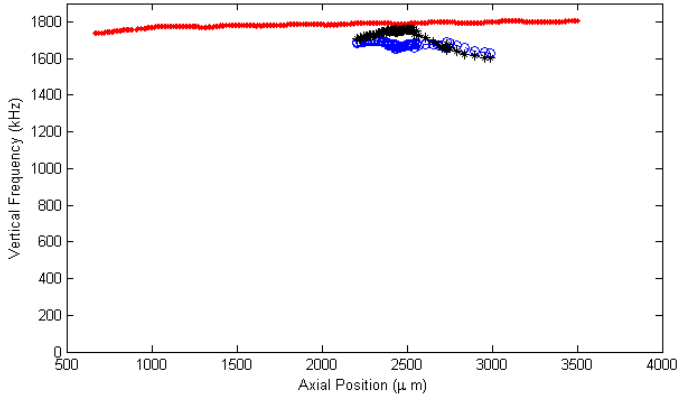



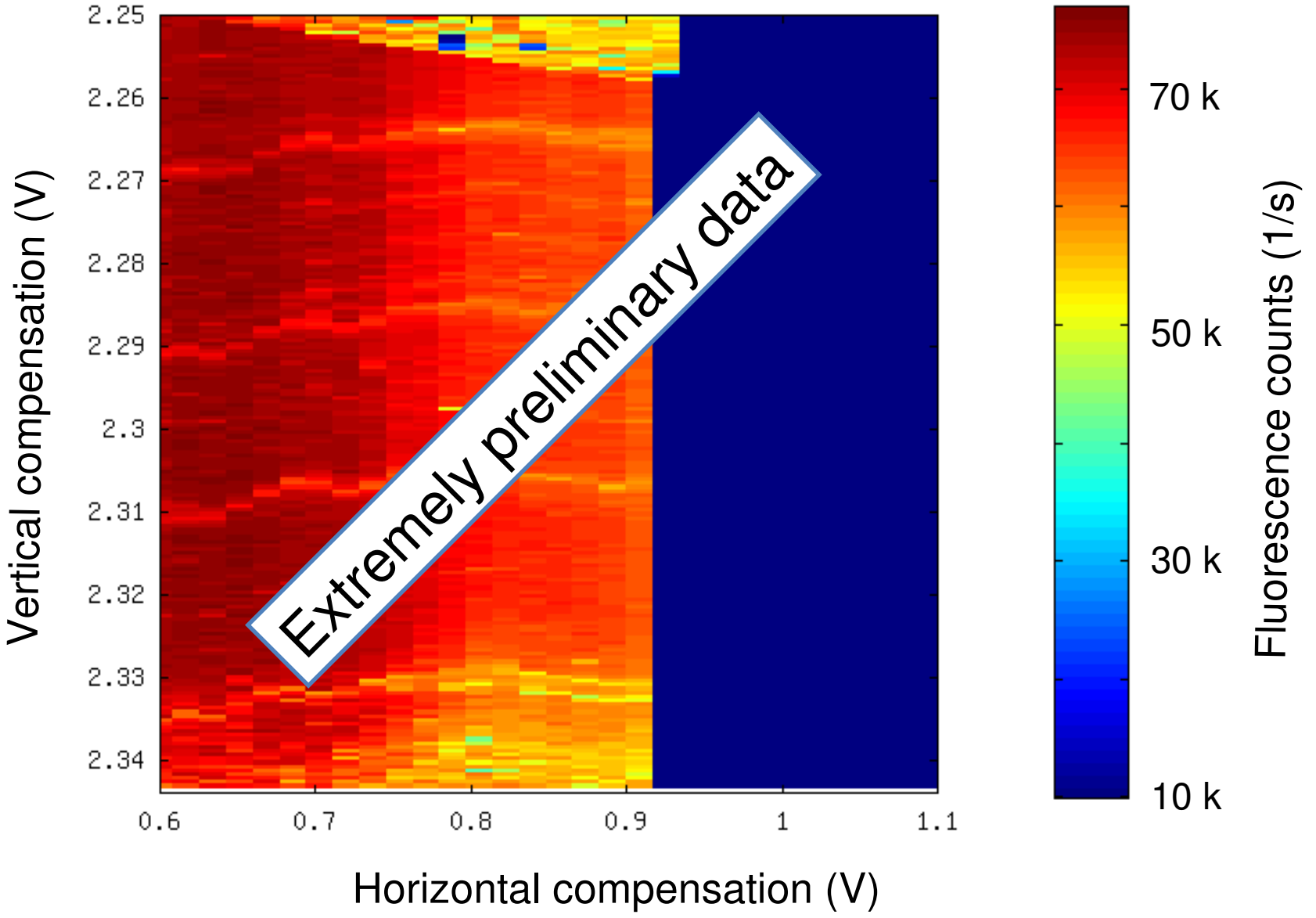
# Trap frequencies



# Stability diagramm



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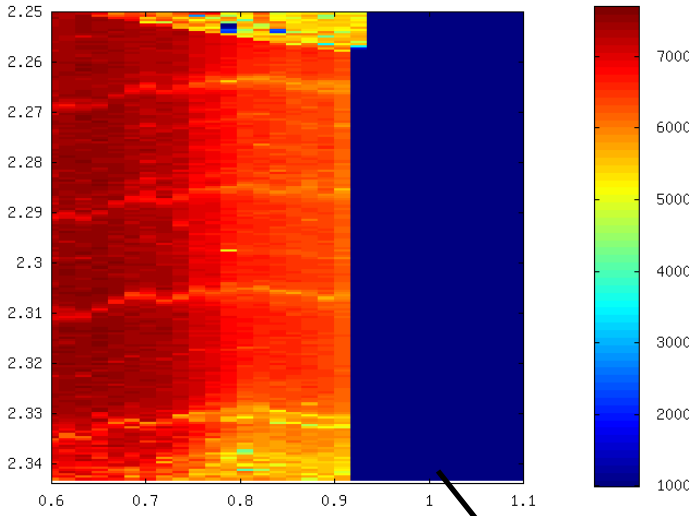
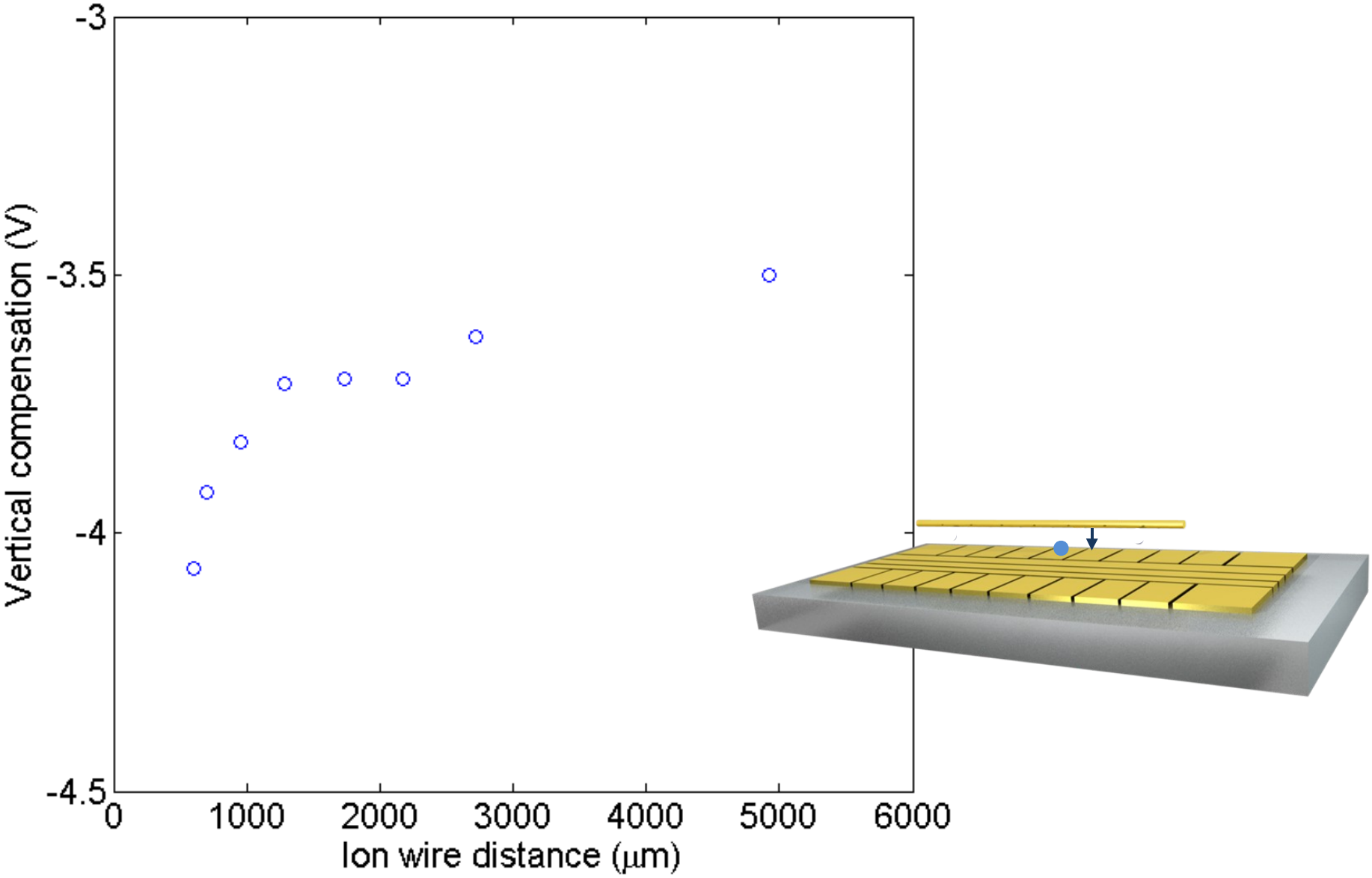


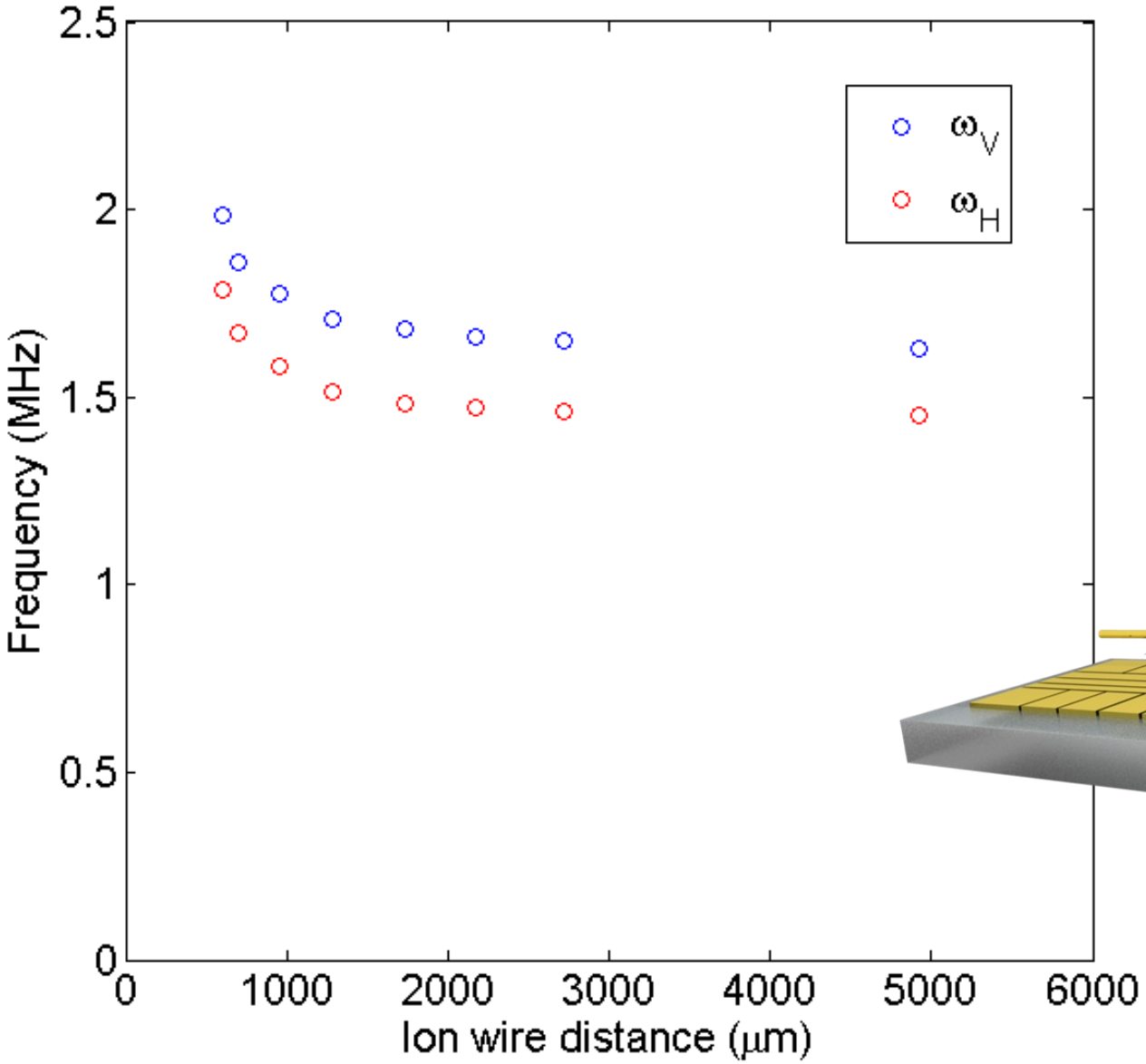

Towards compensated trap

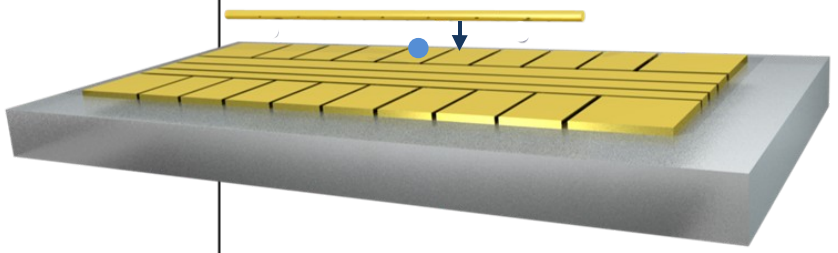
# Experimental set-up

# Moving the wire closer

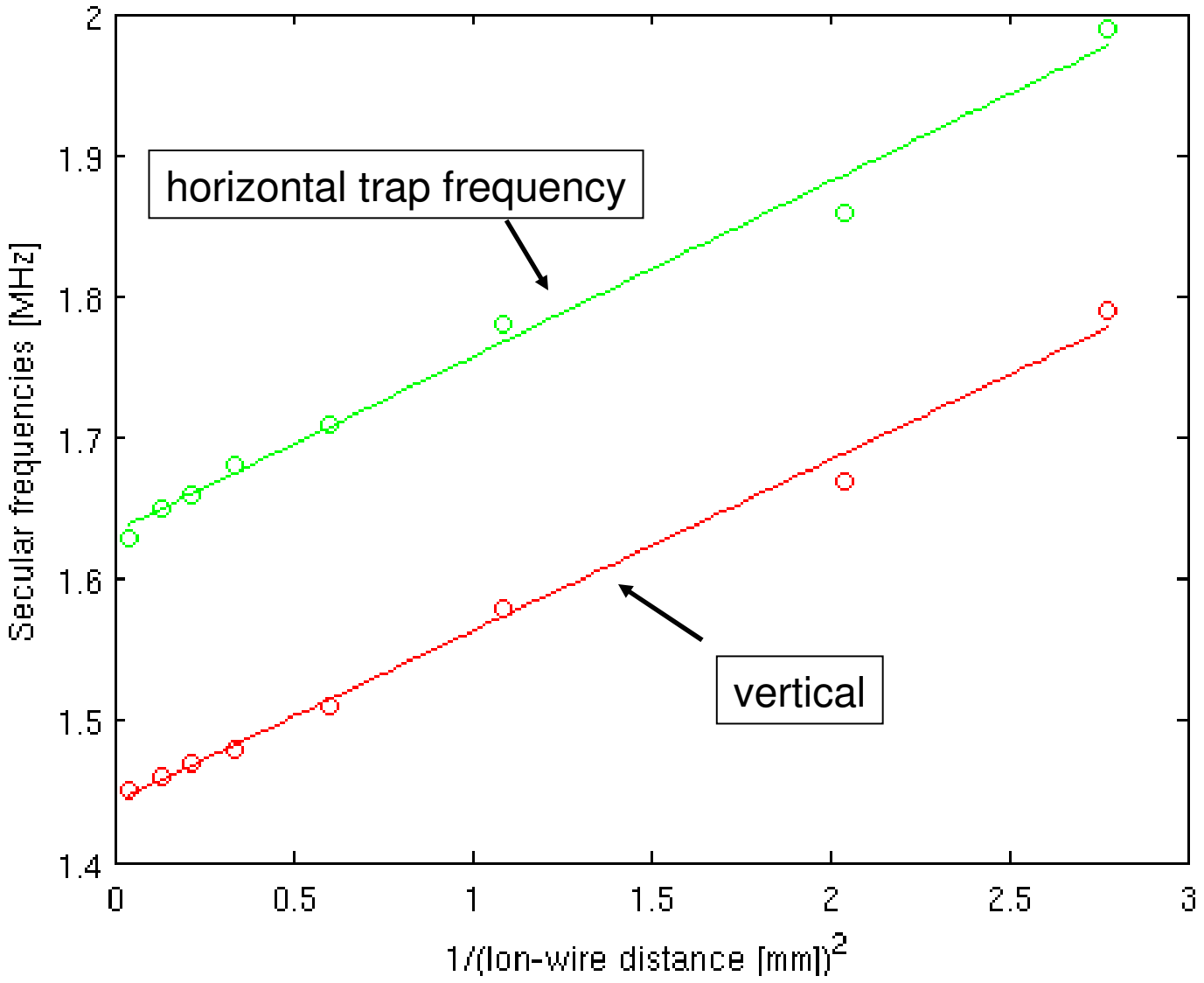


# Moving the wire in

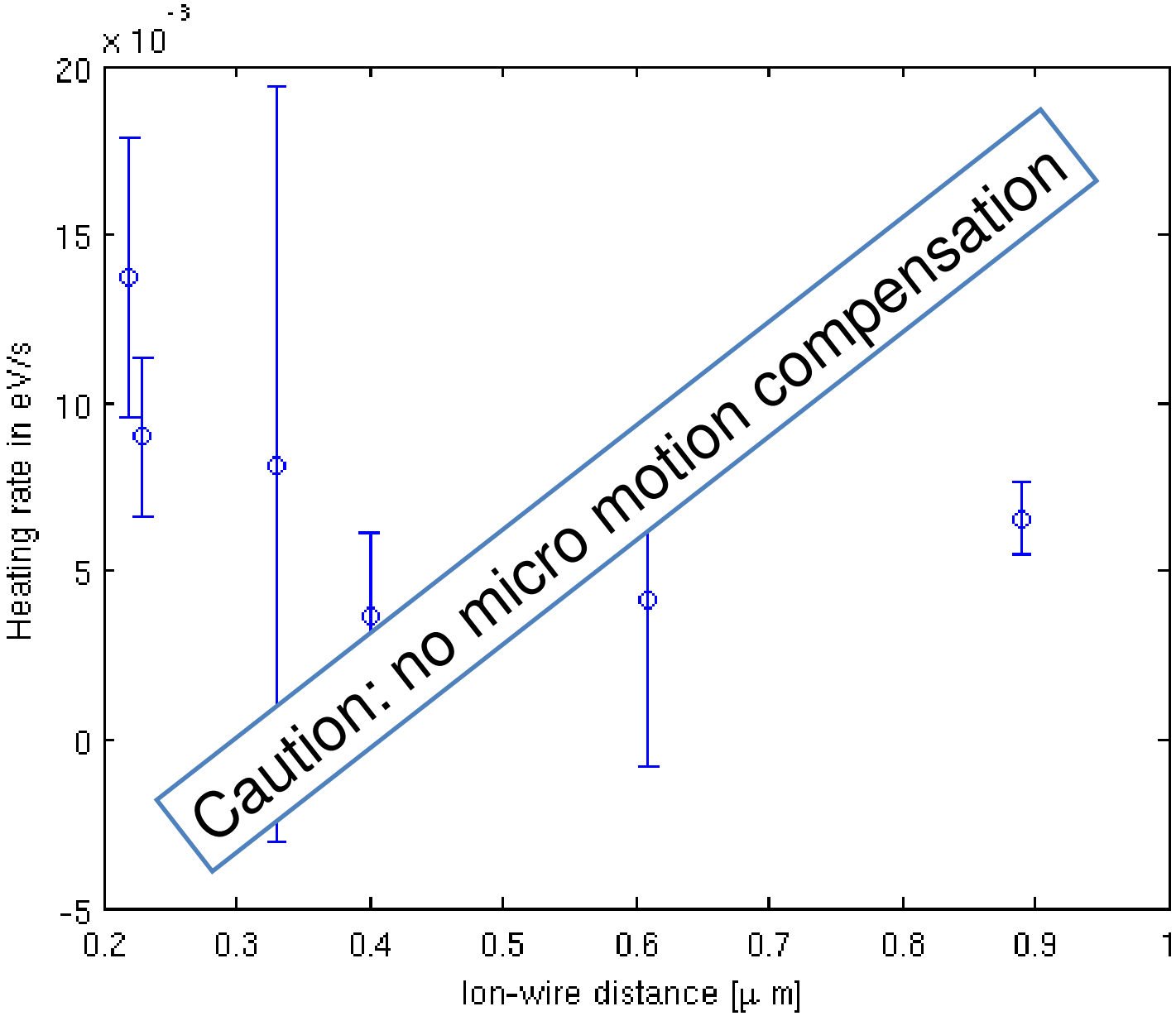


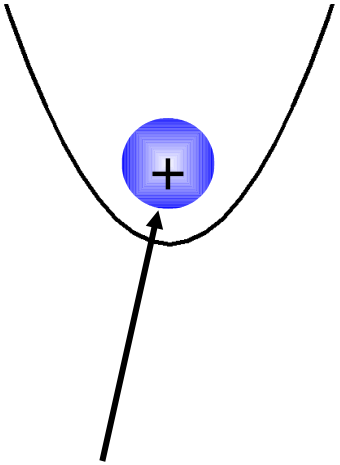
# Moving the wire in



# Moving the wire in



# Quantum sensors

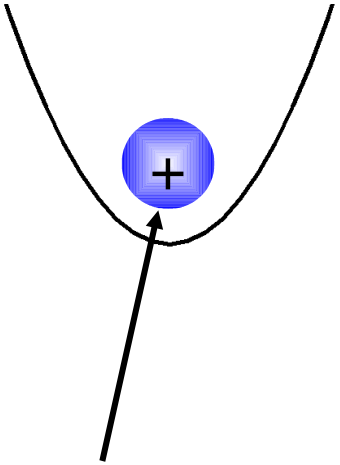


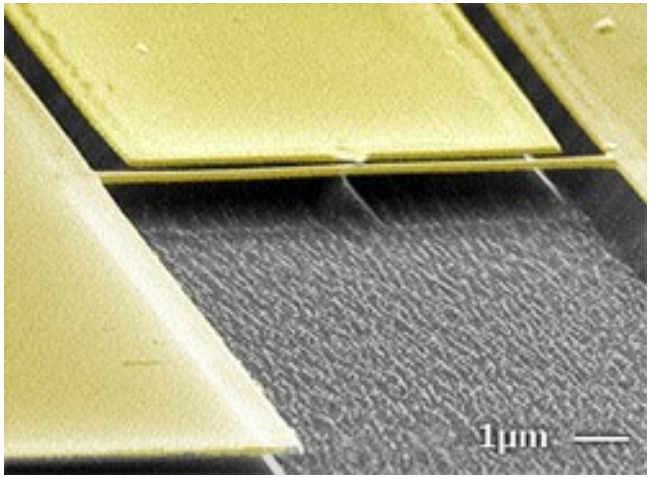
macroscopic object

Quantum sensor

Ultimate control and detection

# Quantum sensors



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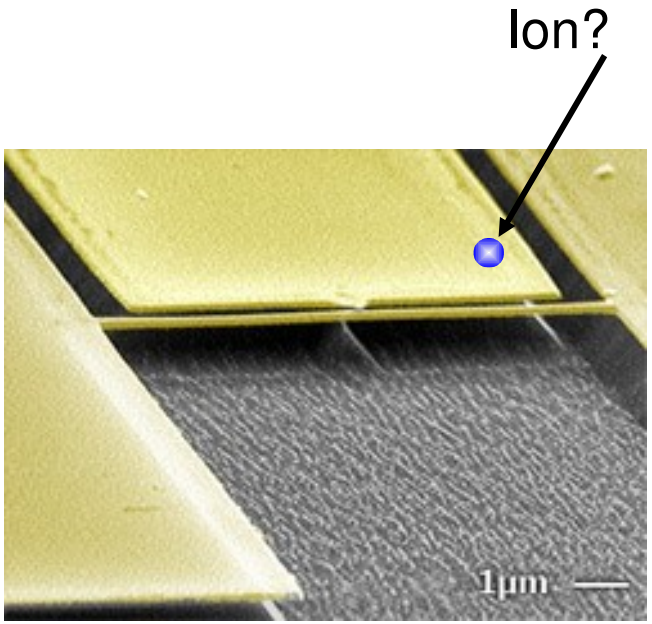
Quantum sensor

Ultimate control and detection

# Quantum sensors

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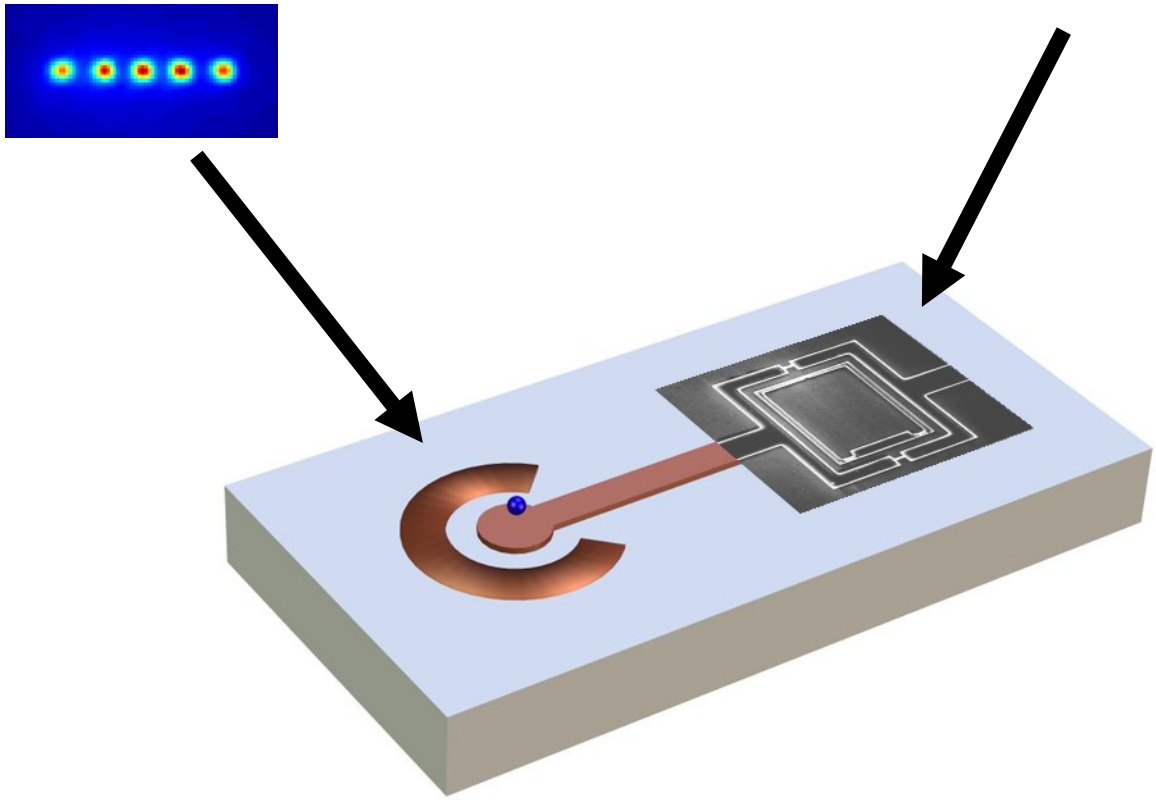
See: L. Tian, P. Zoller, PRL 9**3**, 266403 (2004).
W. K. Hensinger, PRA **72**, 041405R (2005).

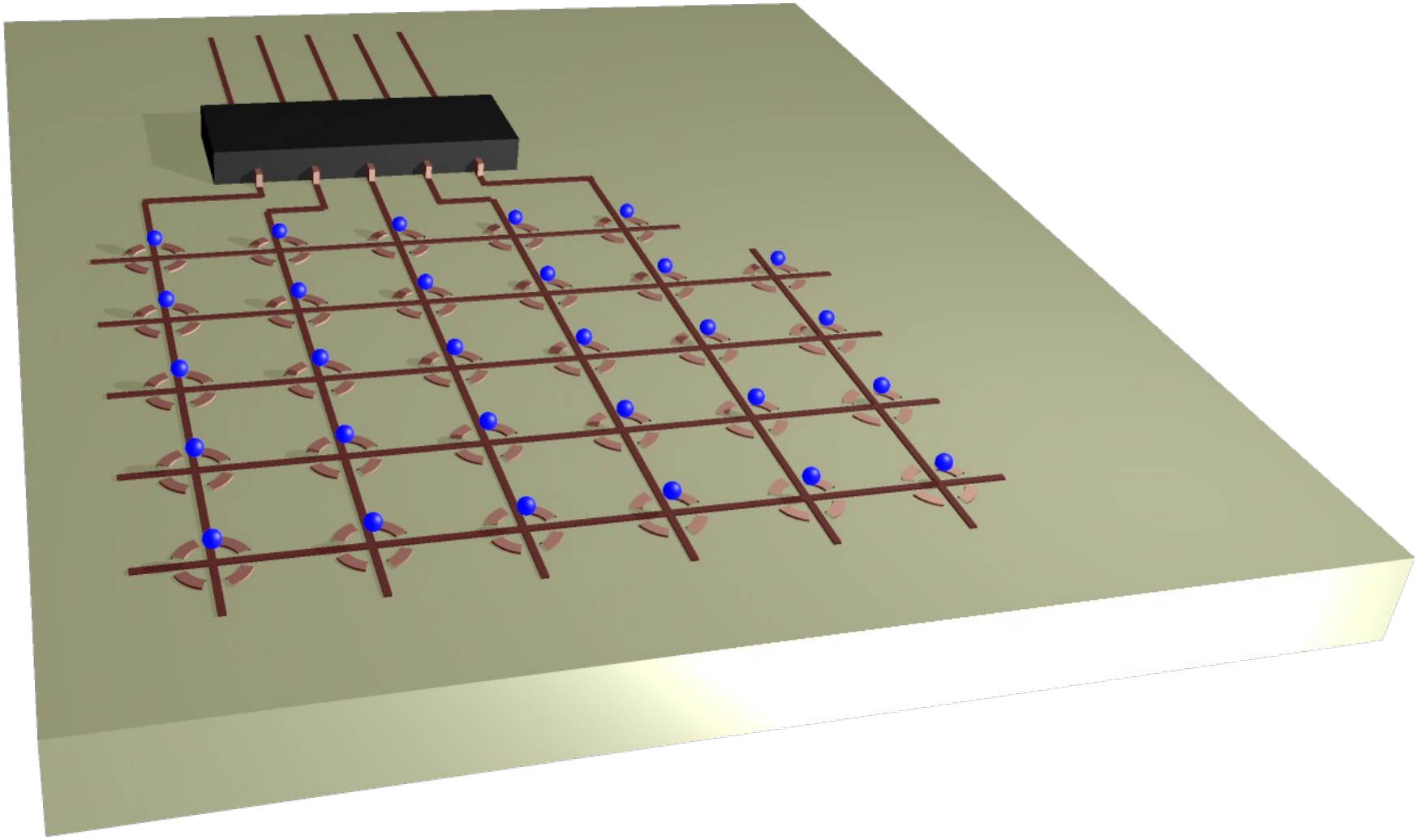
# Hybrid devices

Trapped ions

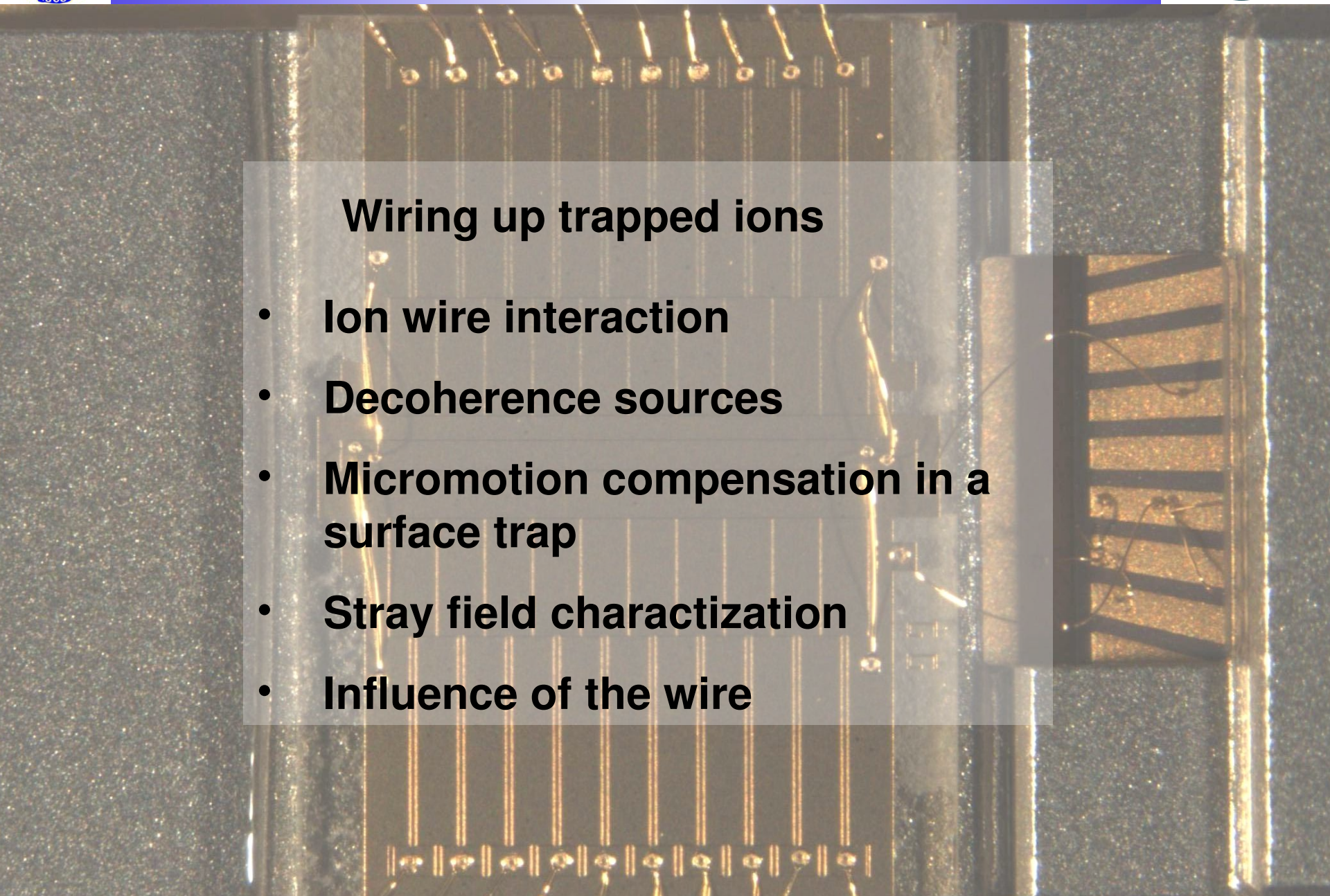
Josephson qubits



# A vision



# Summary



**Wiring up trapped ions**

- **Ion wire interaction**
- **Decoherence sources**
- **Micromotion compensation in a surface trap**
- **Stray field charactization**
- **Influence of the wire**