Wiring up trapped ions

Hartmut Häffner

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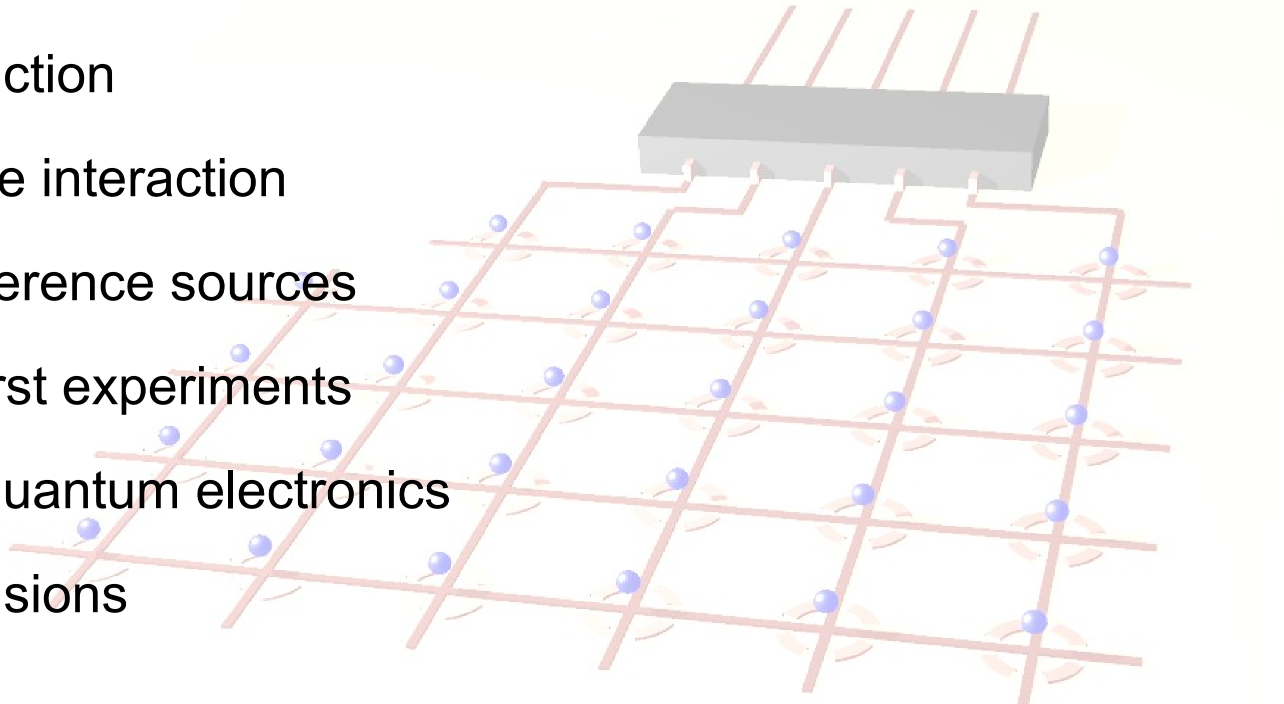
- Introduction
- Ion-wire interaction
- Decoherence sources
- Very first experiments
- More quantum electronics
- Conclusions



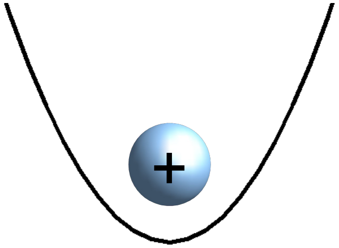
FWF bm:bwk

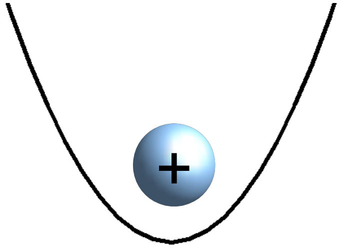
U.S. AIR FORCE

GTQI, Oct 31st 2011

Wiring up trapped ions

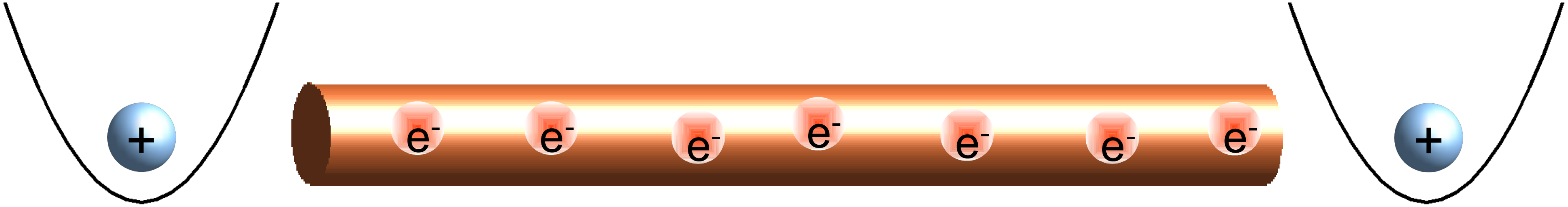
Two trapped ions …





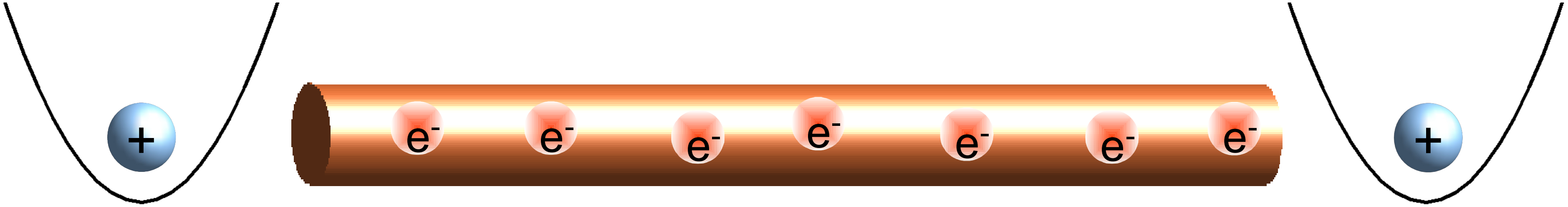
Wiring up trapped ions

Two trapped ions + a wire



Wiring up trapped ions

Transport of quantum information



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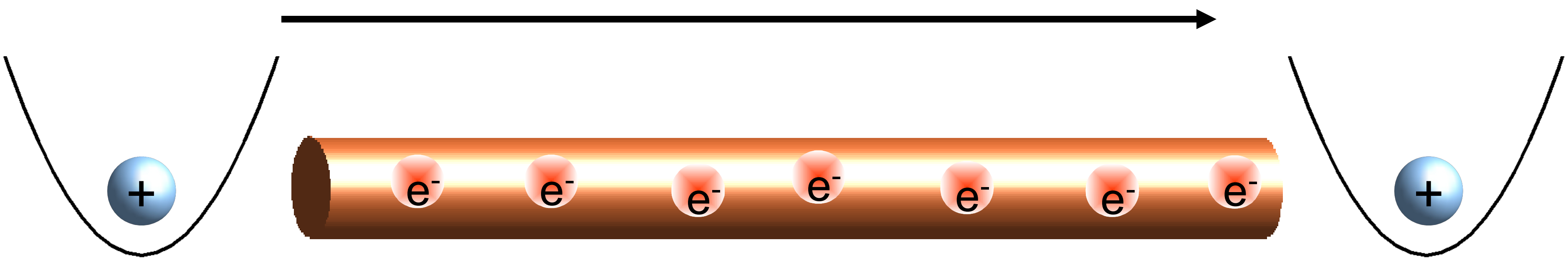
Transport of quantum information



No trace of the quantum information should remain in the wire

➡ ~~super conducting~~ wire

Applications

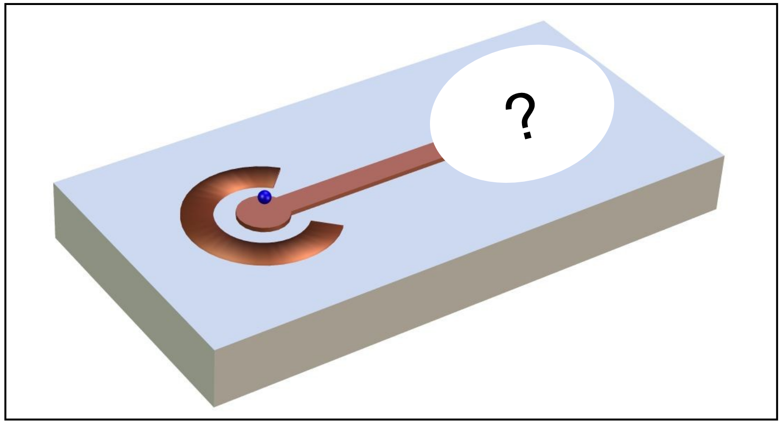
Physics:

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

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

Technology:

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



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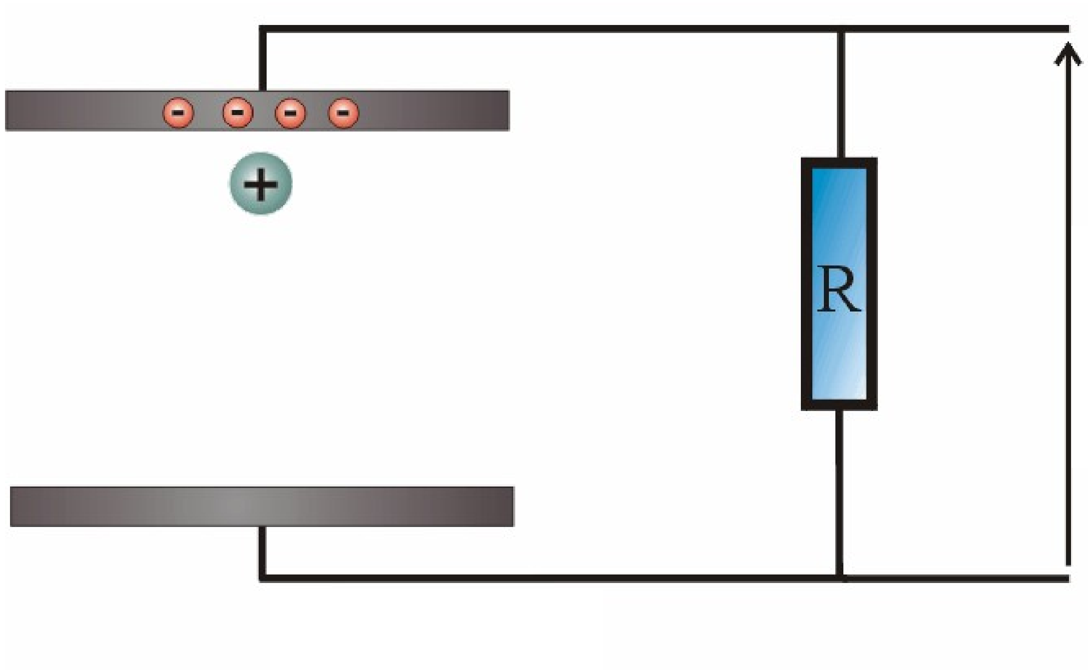
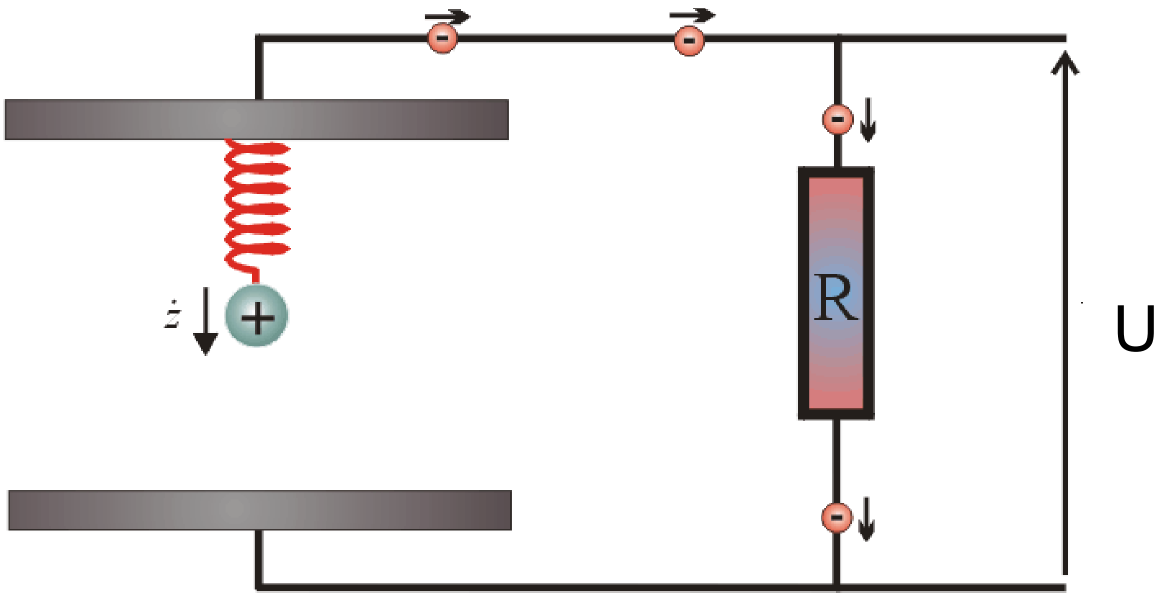
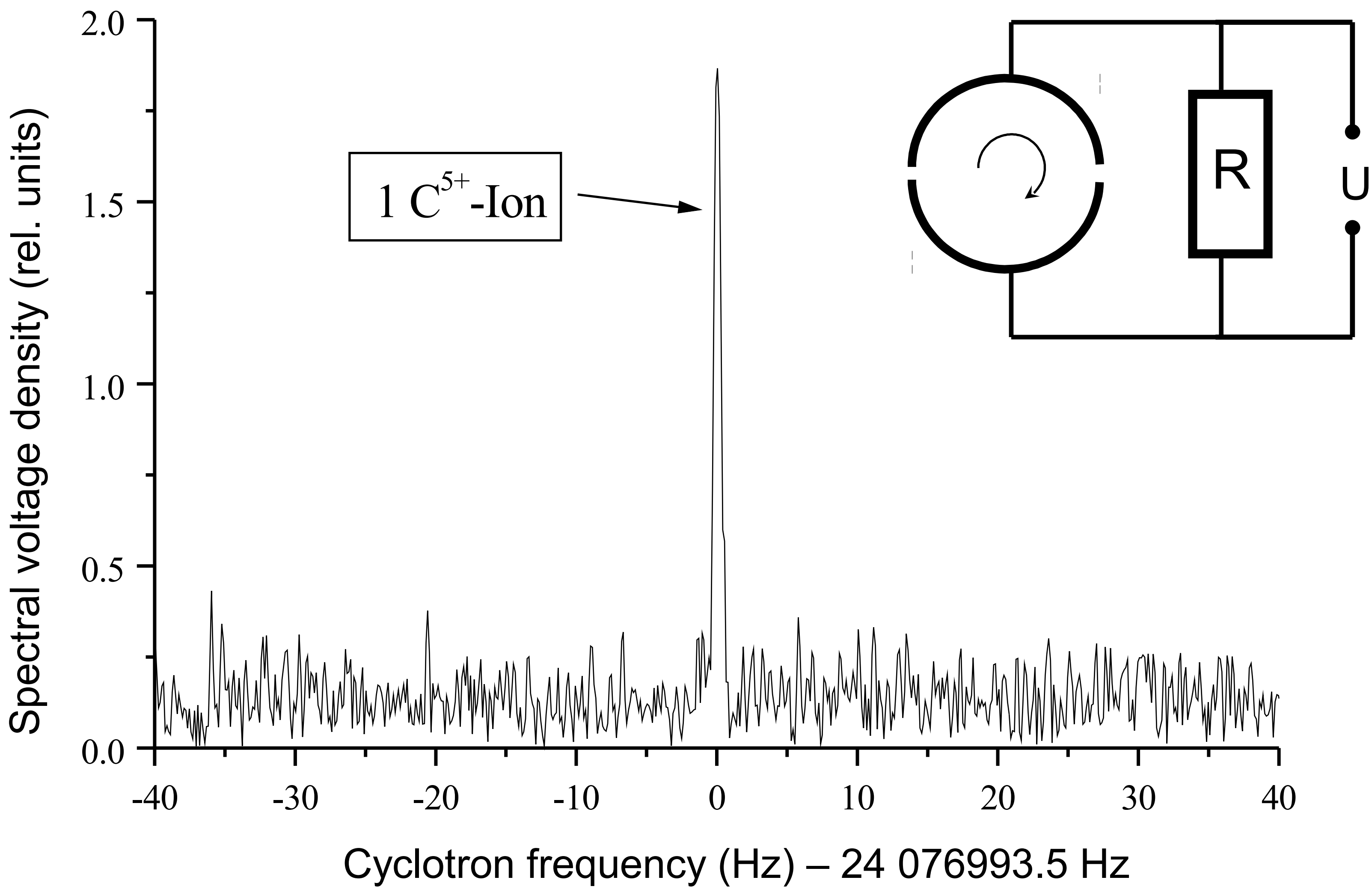
Ion-electronics



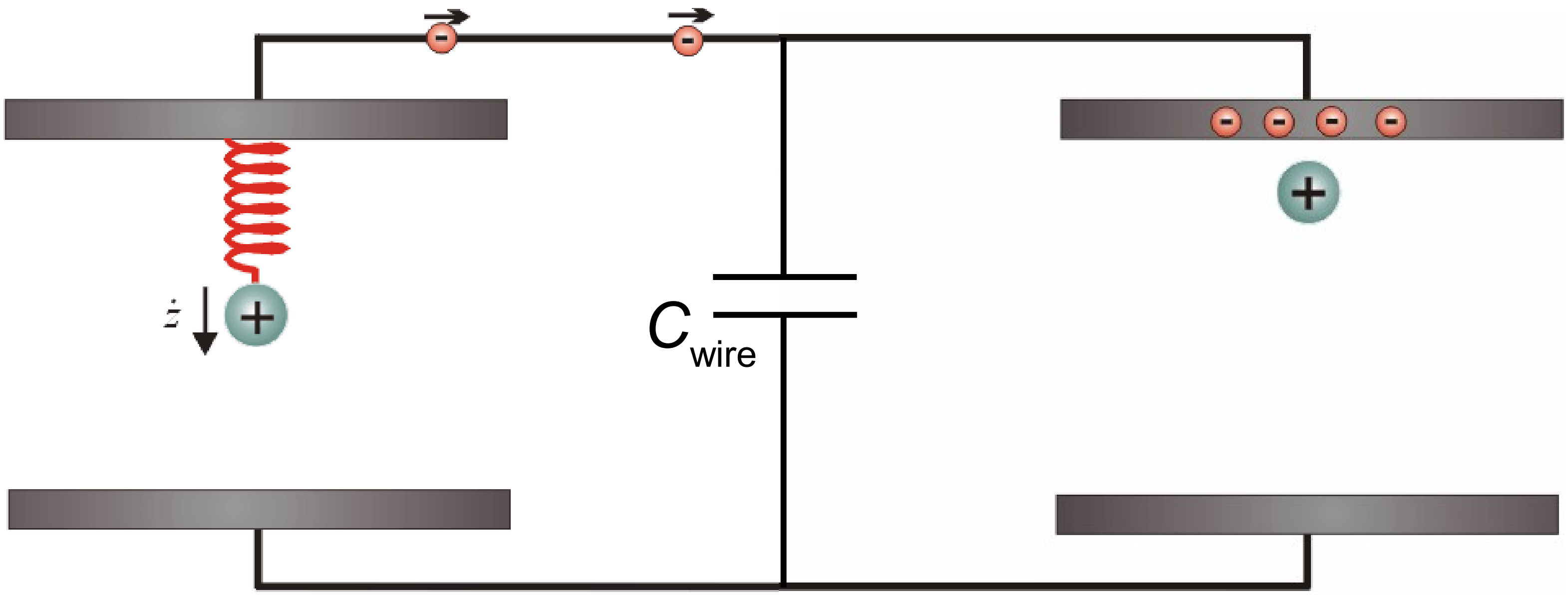
Ion-electronics



Ion-electronics

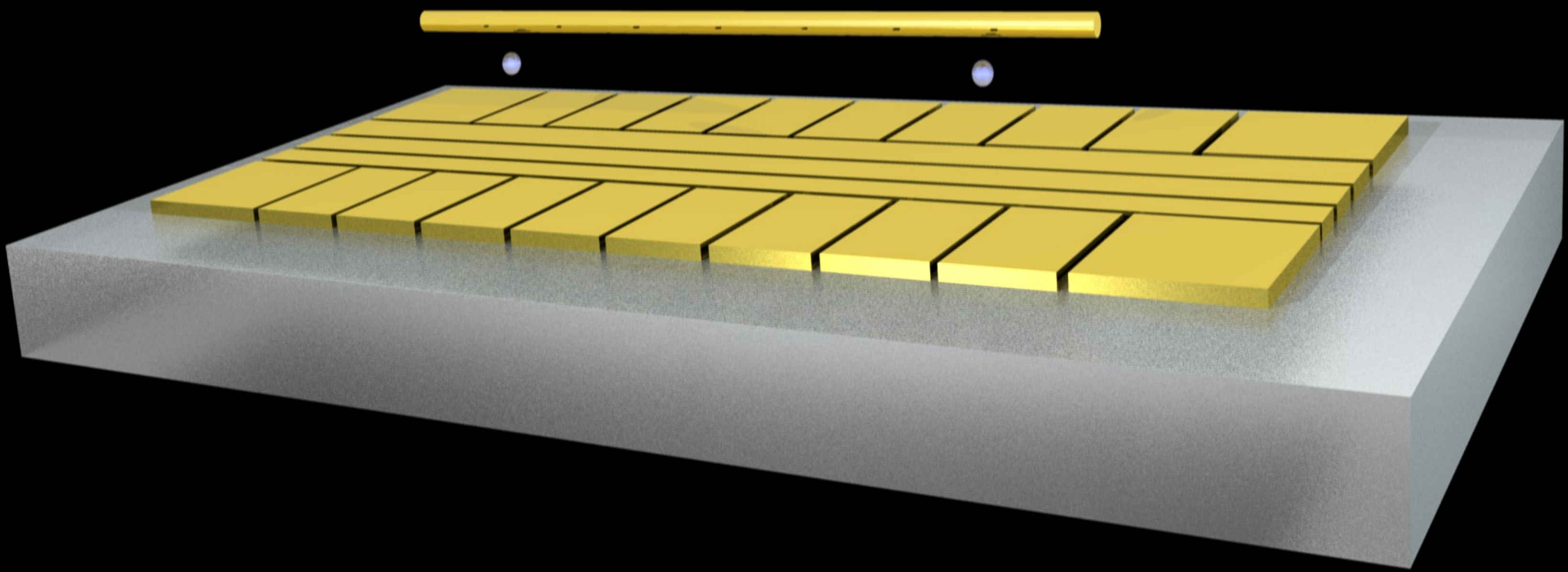


Wiring up ions

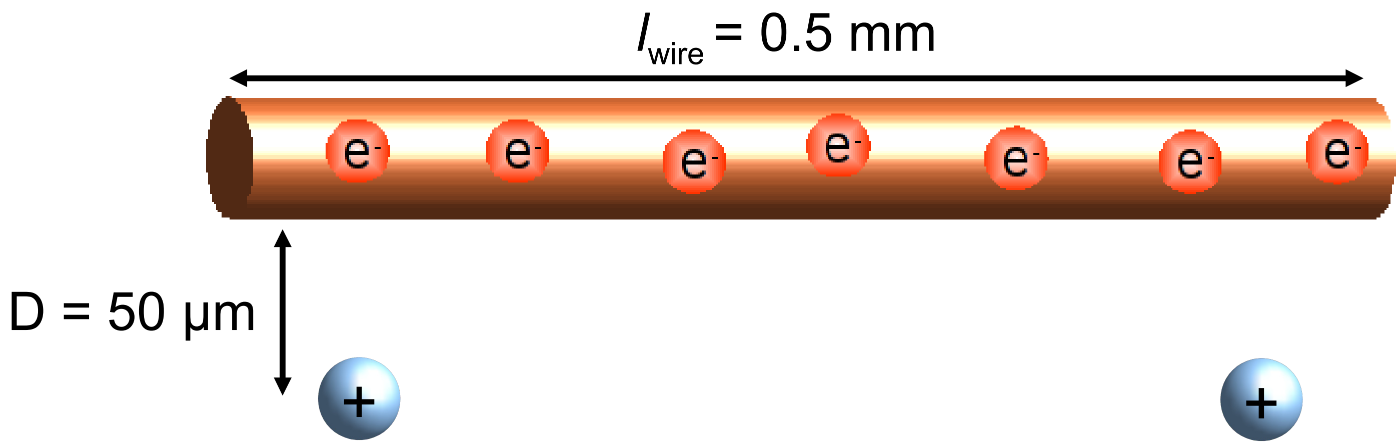


Energy exchange rate: $$\frac{1}{T} = \frac{1}{2\pi}\frac{q^2}{mD^2}\frac{1}{\omega}\frac{1}{C_{\text{wire}}}$$

Experimental set-up



Some numbers



Projected numbers:

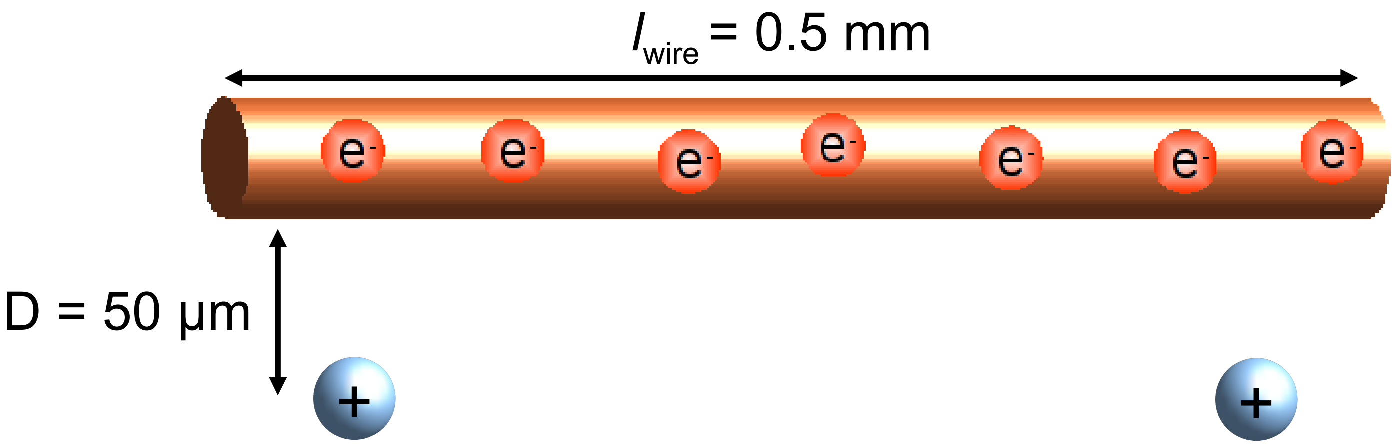
D_{eff} = 3.6 x 50 μm

ω =2π x 500 kHz

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

γ = 2π x 100 Hz

Some numbers



Achieved numbers:

$D_{eff} = 3.6 \times 300\ \mu m$

$\omega = 2\pi \times 500$ kHz

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

γ would be $2\pi \times 0.14$ Hz

Projected numbers:

$D_{eff} = 3.6 \times 50\ \mu m$

$\omega = 2\pi \times 500$ kHz

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

$\gamma = 2\pi \times 100$ Hz

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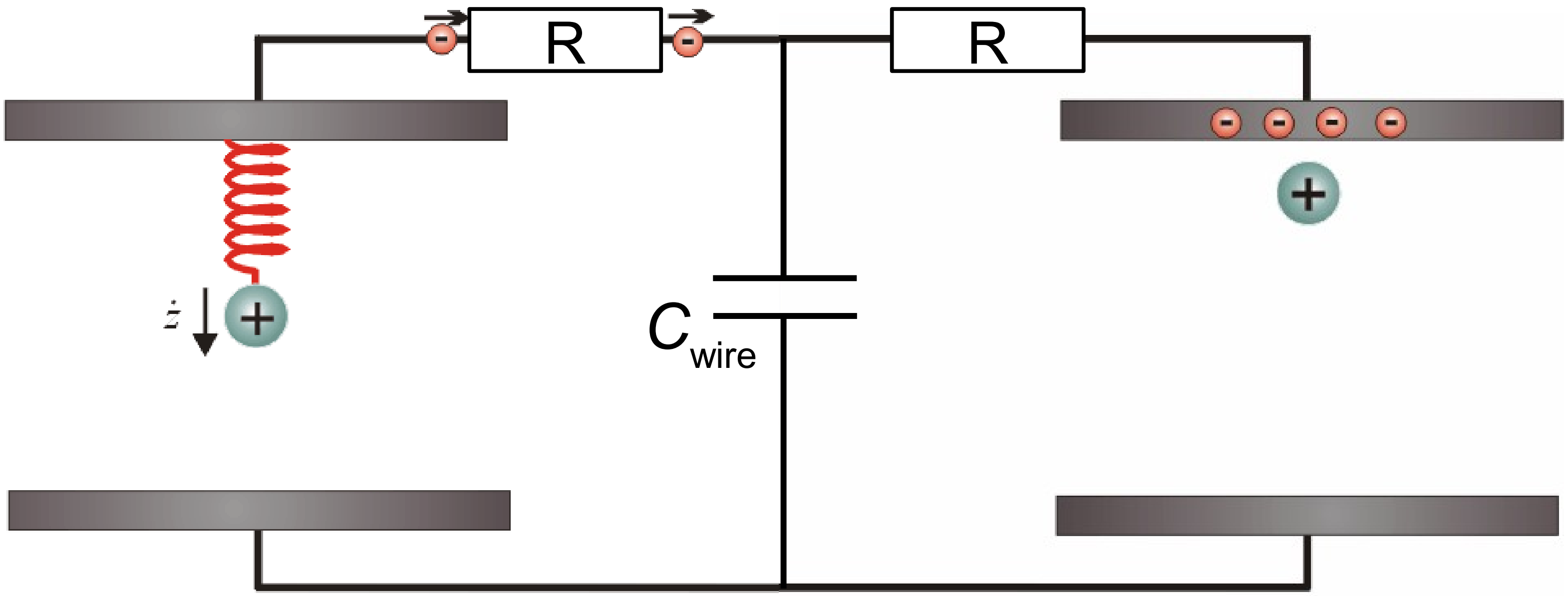
Coupling



with $I = \frac{q}{D}\dot{x}$

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

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

Decoherence sources

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

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

Decoherence sources

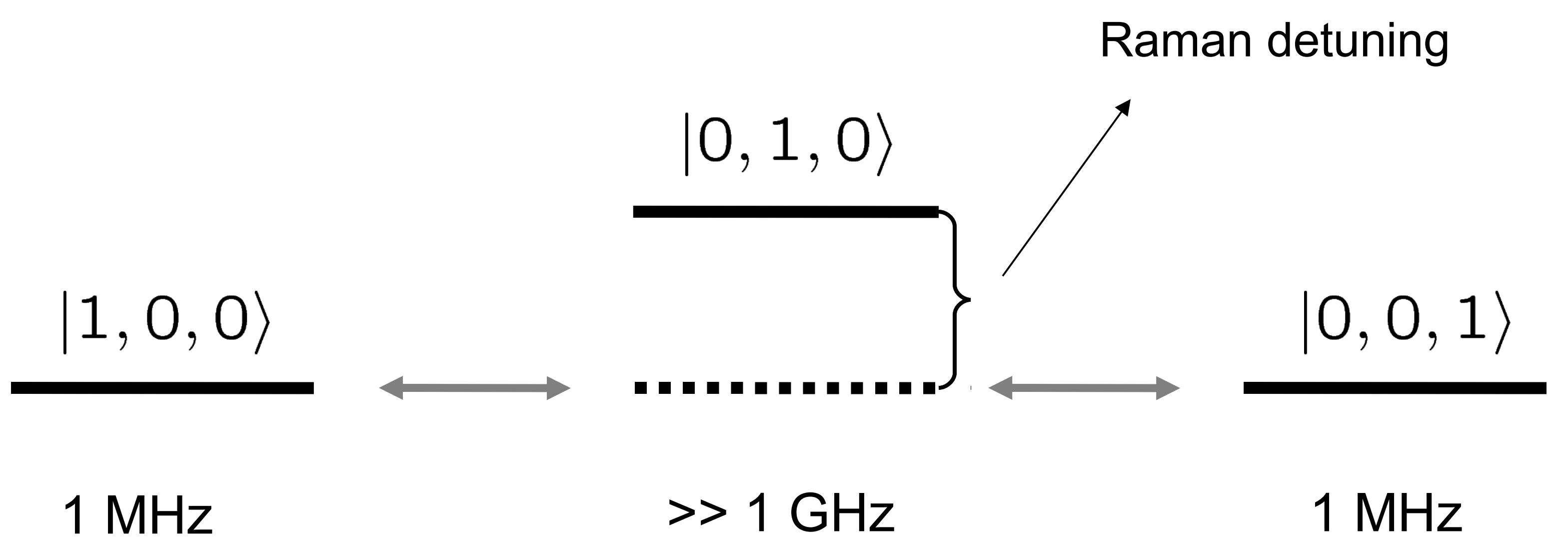
Three coupled harmonic oscillators:

$$|1,0,0\rangle \longleftrightarrow |0,1,0\rangle \longleftrightarrow |0,0,1\rangle$$

$$|\mathrm{ion}_1, \mathrm{wire}, \mathrm{ion}_2\rangle$$

Decoherence sources

Three coupled harmonic oscillators:



Decoherence sources

Dissipation in the wire

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

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

But what about Johnson noise?

Decoherence sources

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

Johnson noise heating

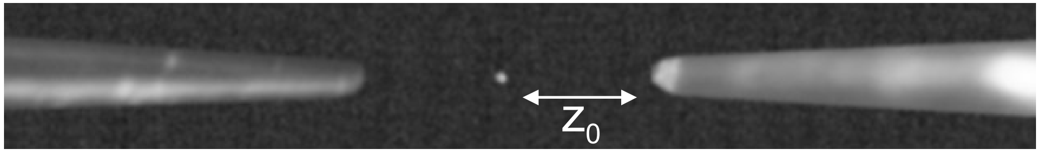
Heating rate : $\gamma_J=\frac{P_J}{\hbar\omega}=\frac{k_B T\gamma}{\hbar\omega}\approx 14\frac{1}{s}$

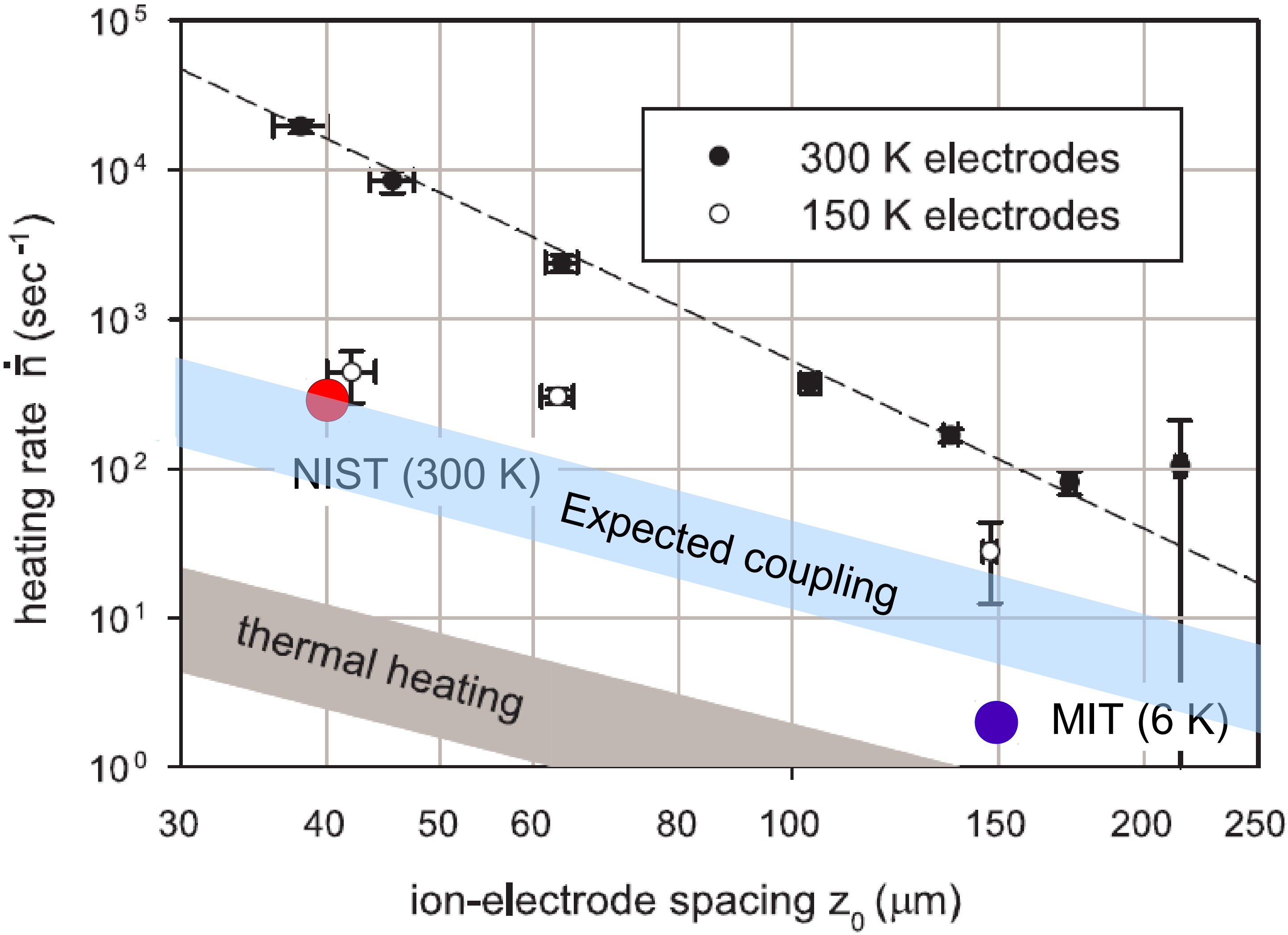
Expected coupling over 0.5 mm: $\gamma_C > 2\pi \times 100\ 1/s$

Decoherence sources

Anything else ?

Anomalous heating





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

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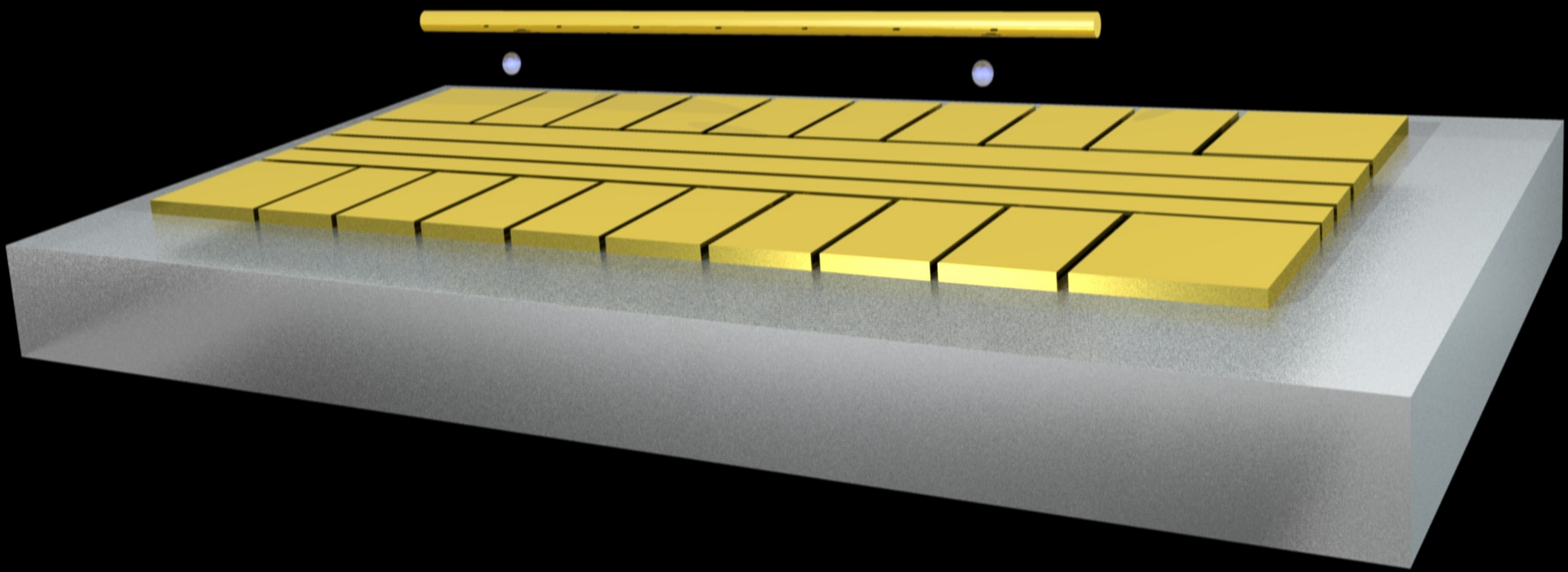
Experimental set-up



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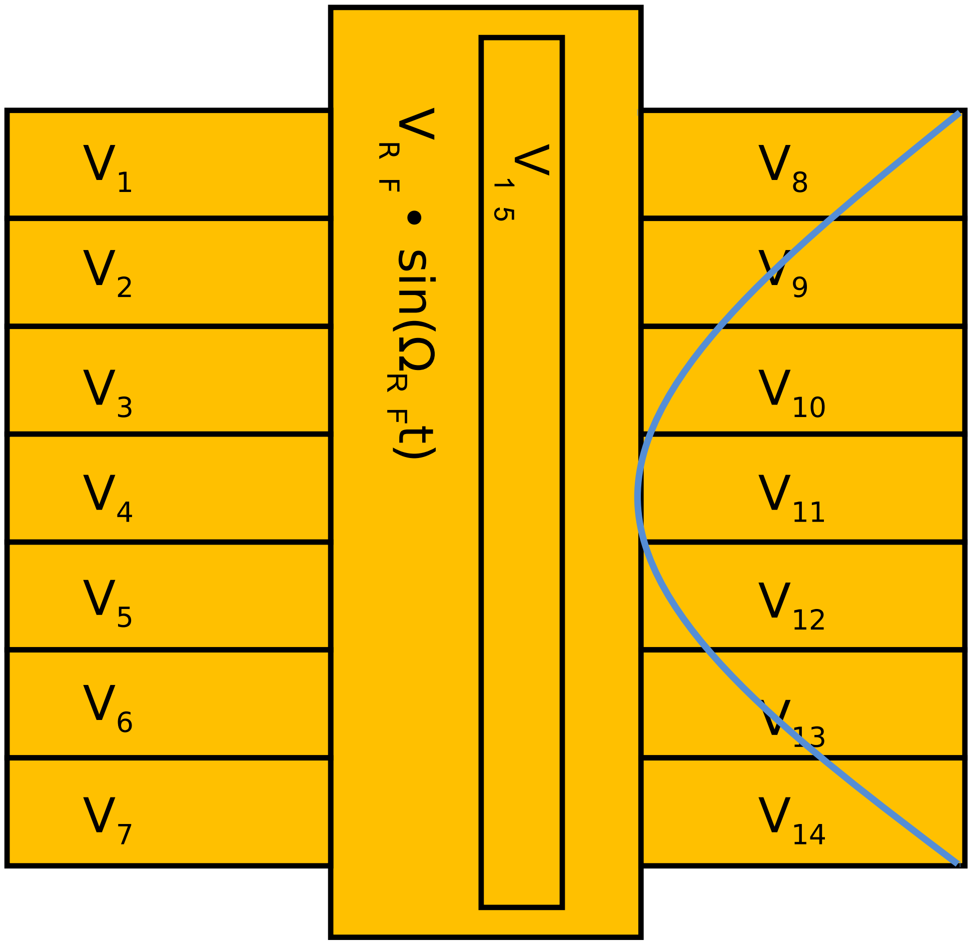
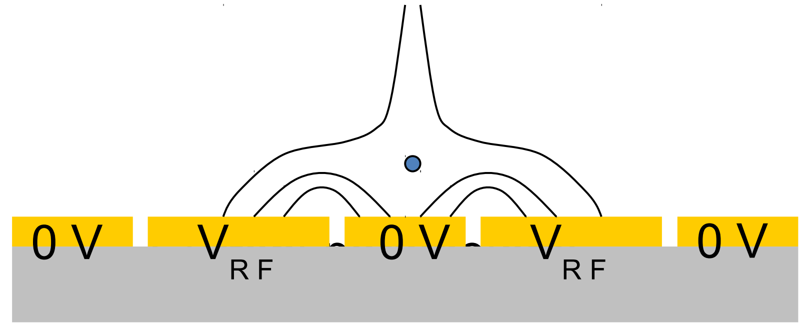




Ion height $\approx 220\ \mu$m

$\Omega_{RF} \approx 2\pi \cdot 15$ MHz

$V_{RF} \approx 100$ V

$V_{DC} < 10$ V

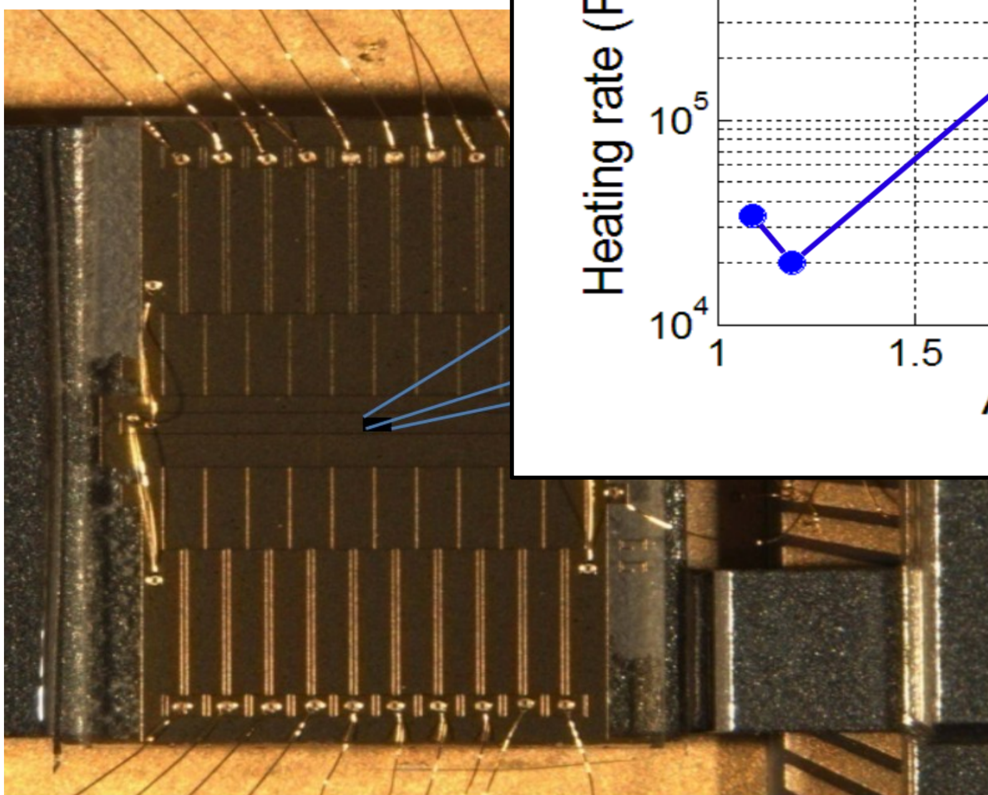
$\omega_H \approx 2\pi \cdot 1.3$ MHz

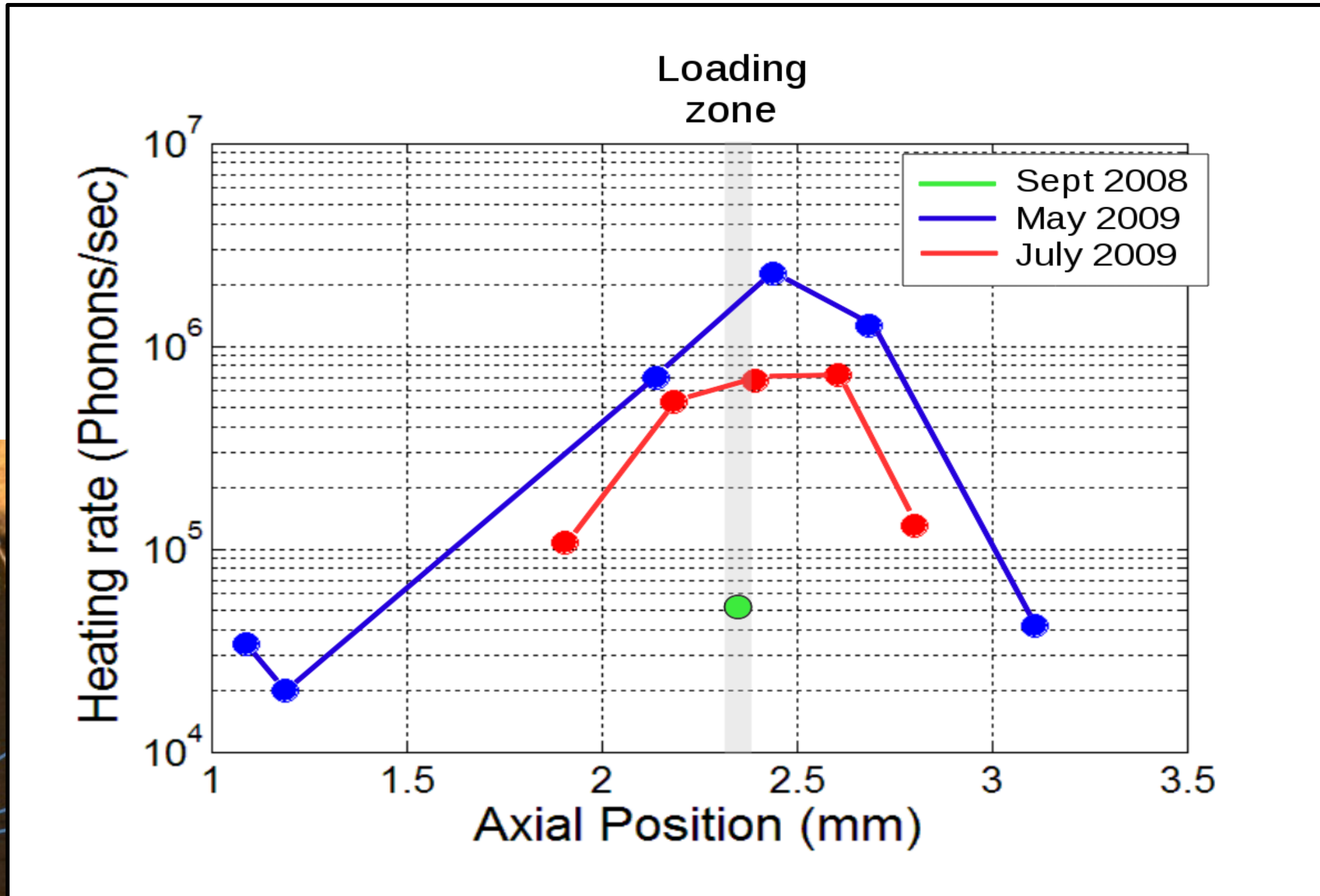
$\omega_V \approx 2\pi \cdot 1.5$ MHz

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

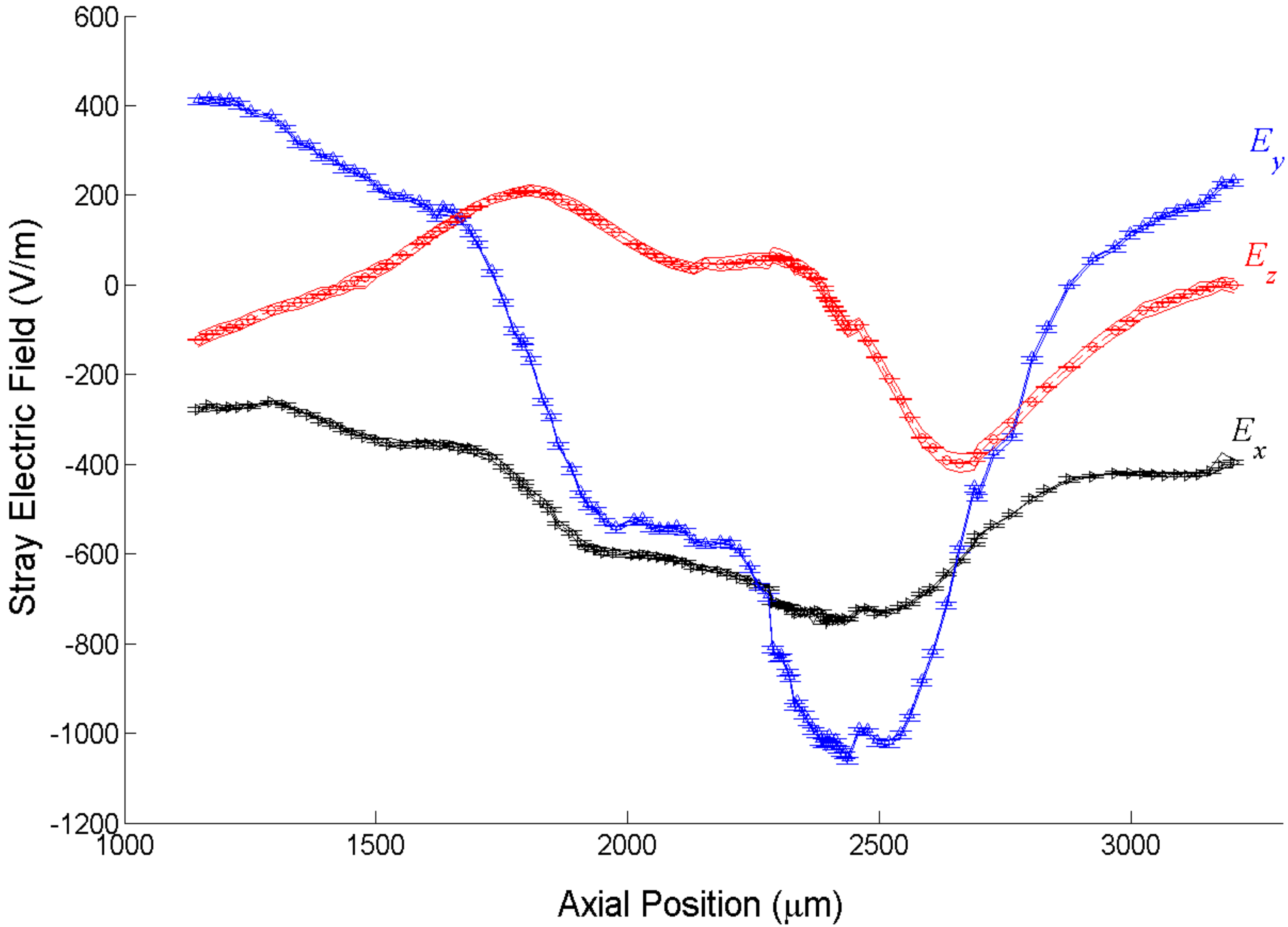
Unknown source for heating

Gold on Sapphire





Derived electric stay fields



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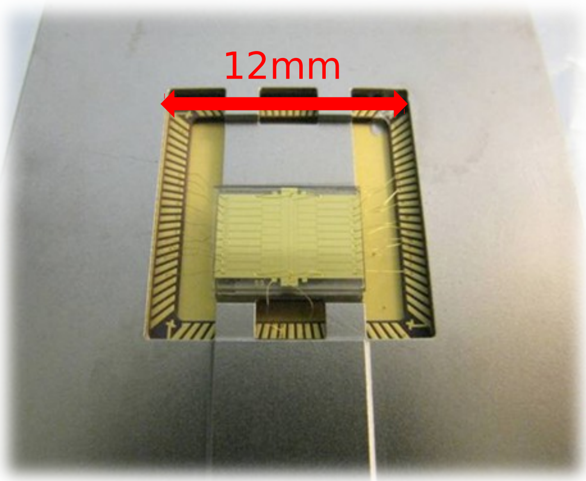
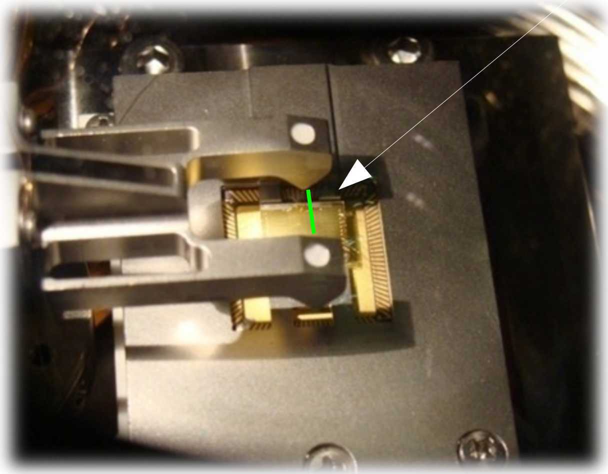


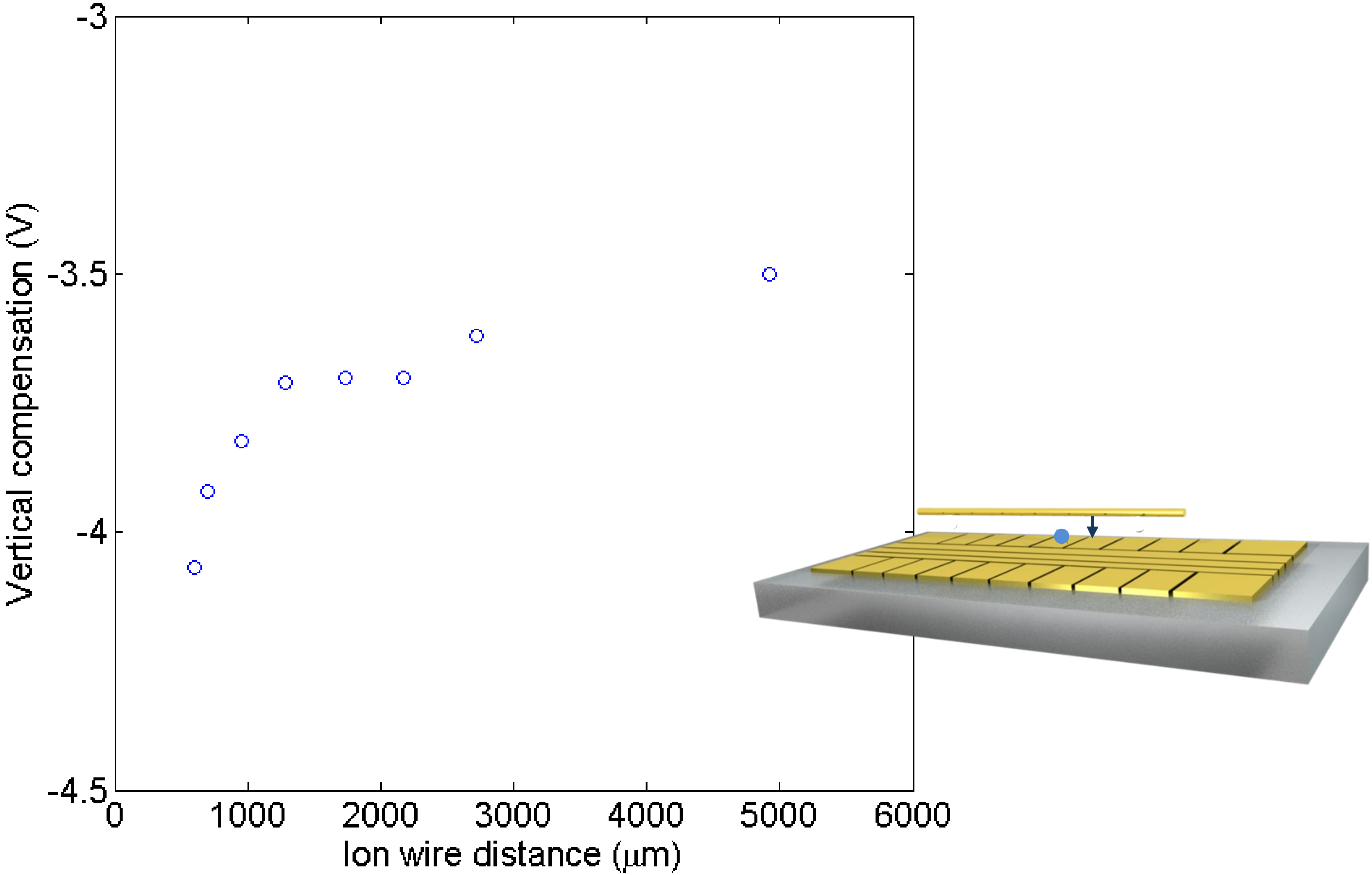
Gold on sapphire microfabricated trap

Wire

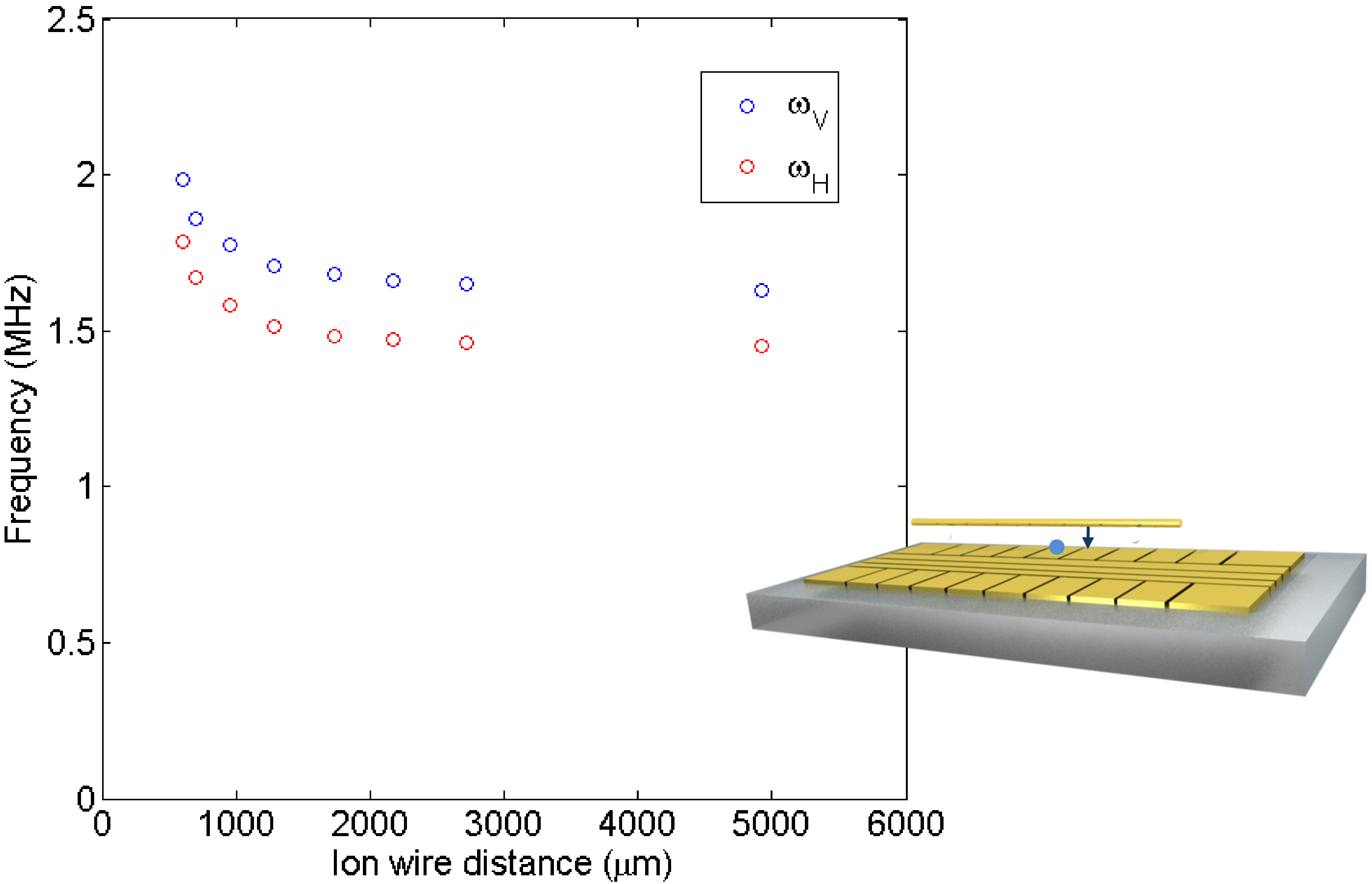


Wire on translation stage

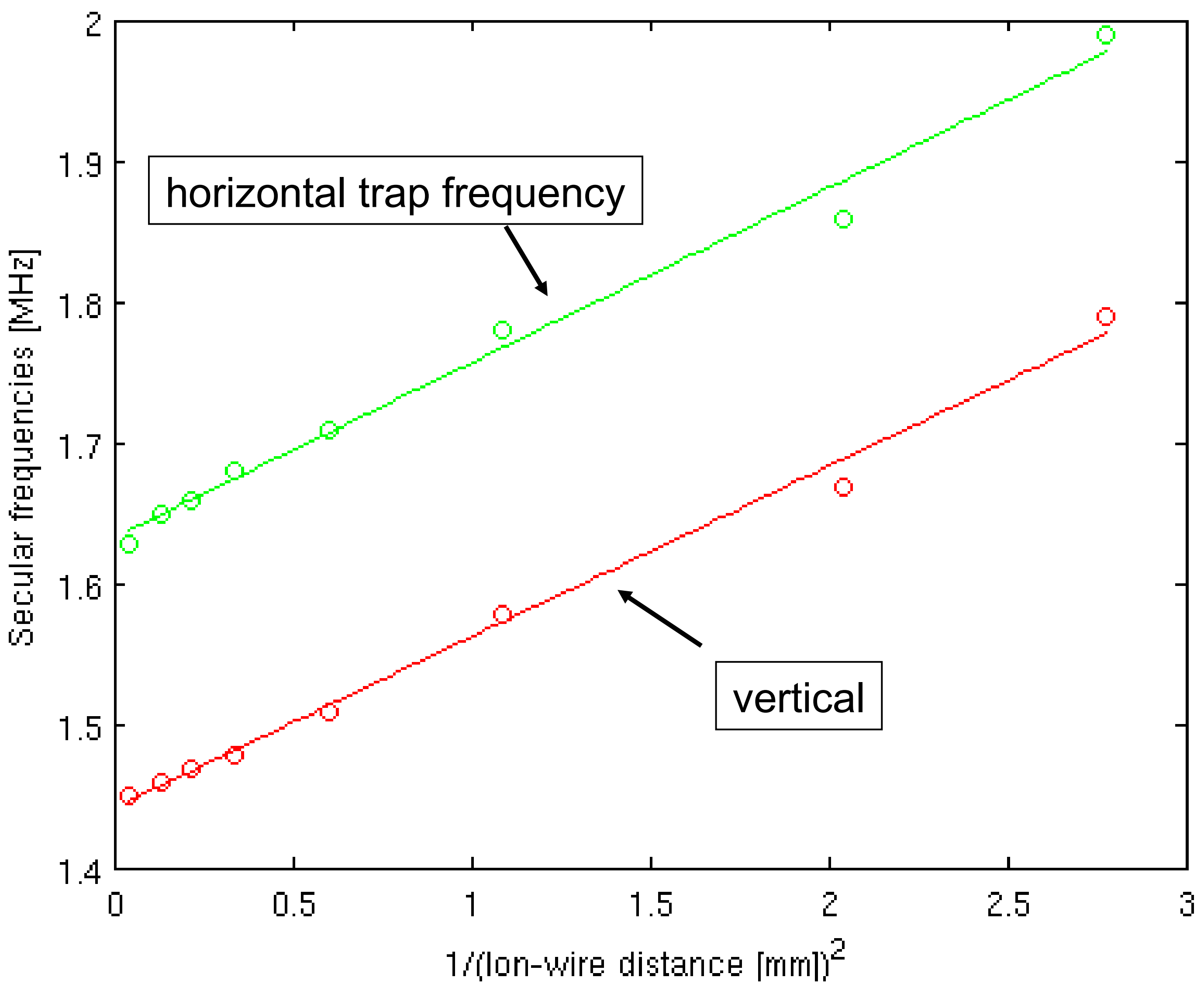
Moving the wire closer



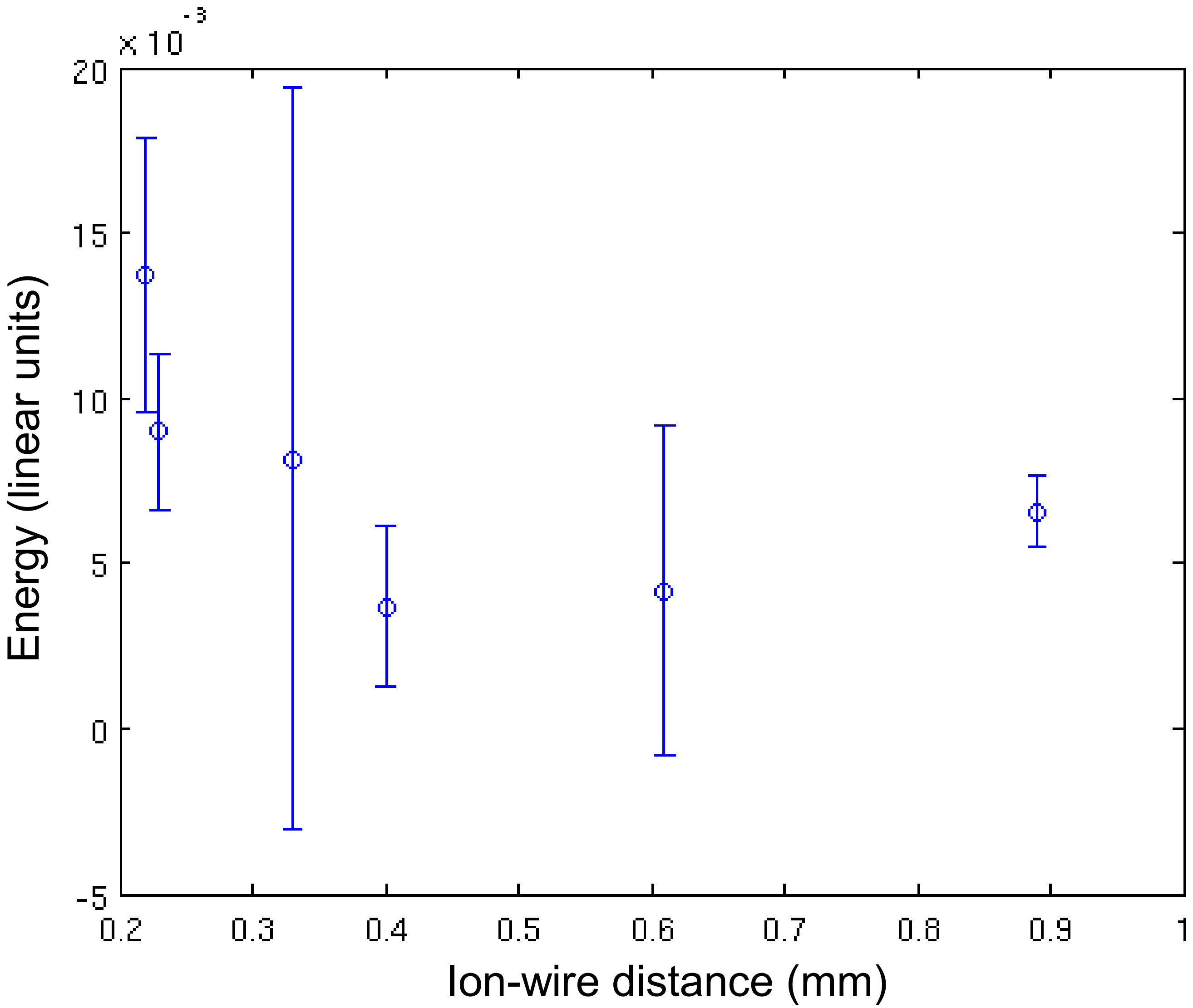
Moving the wire in



Moving the wire in



Heating rates



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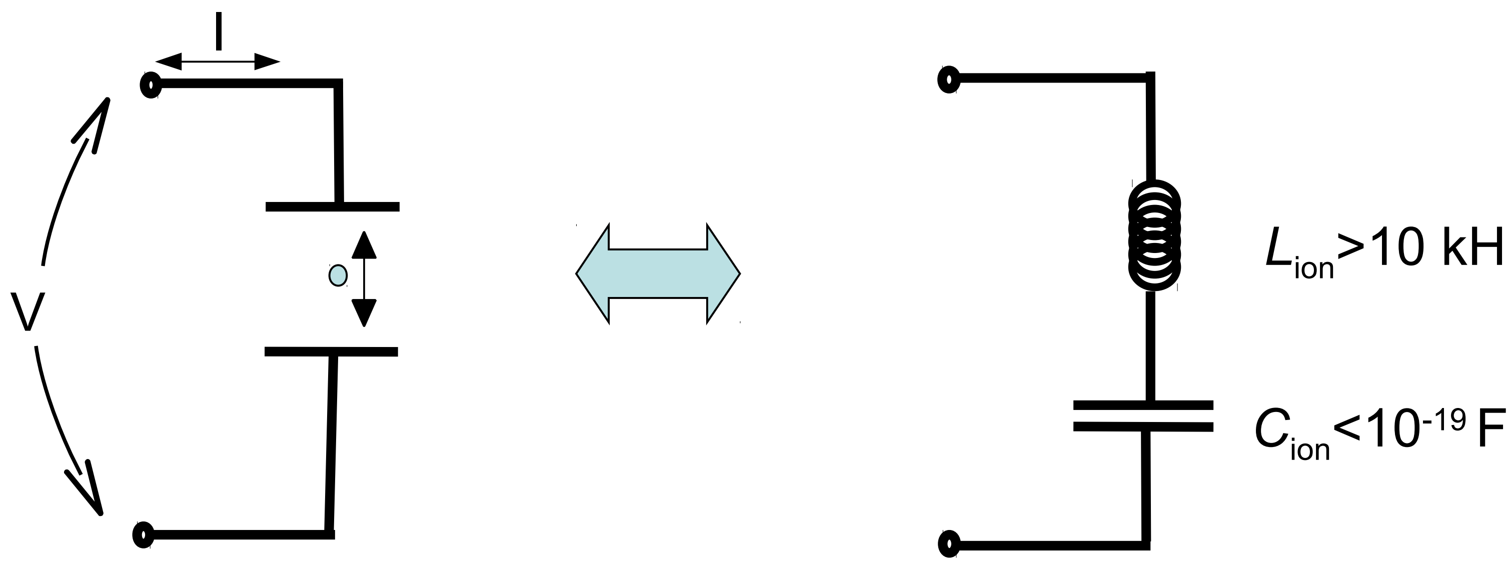
Quantum electronics



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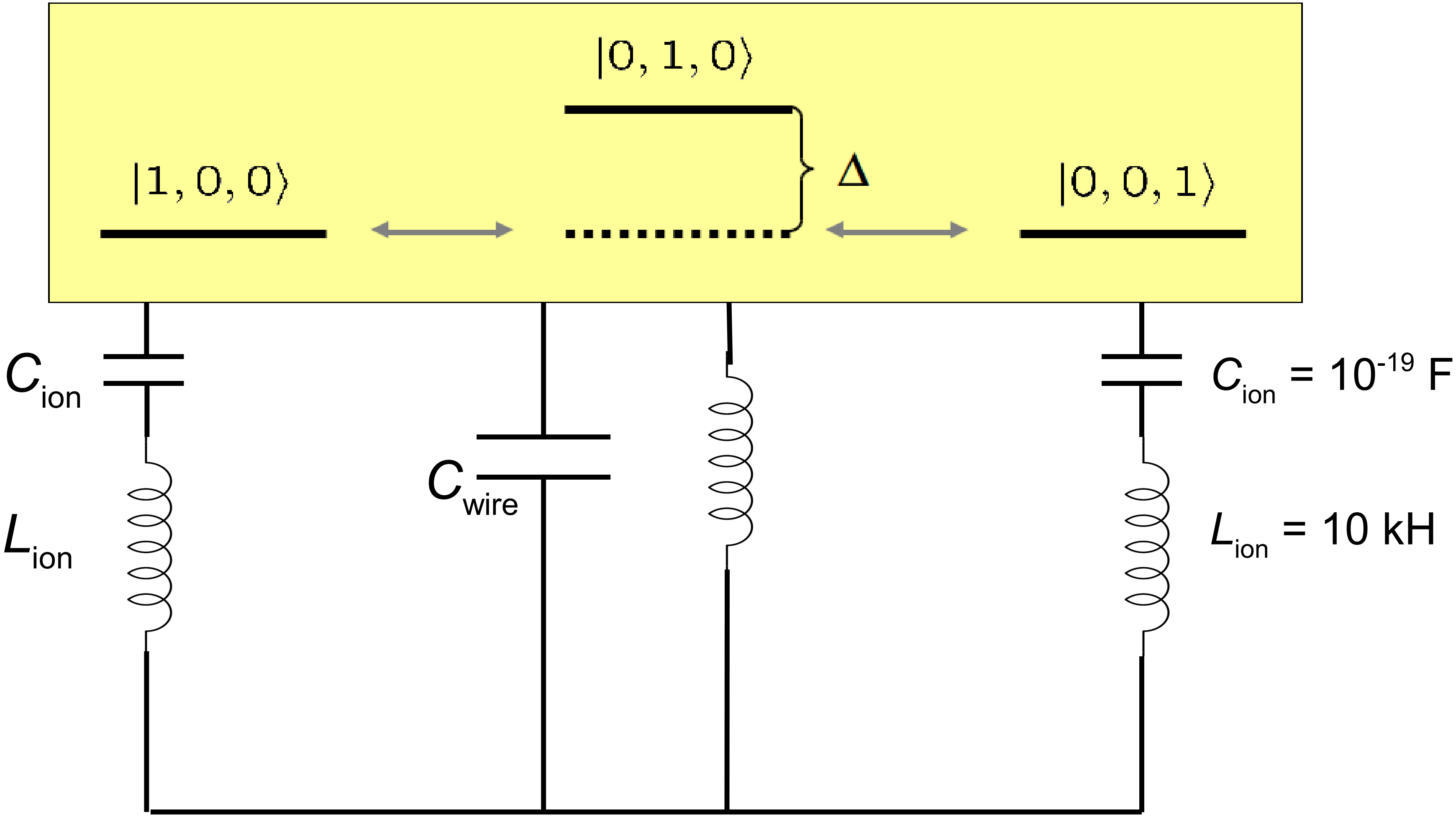
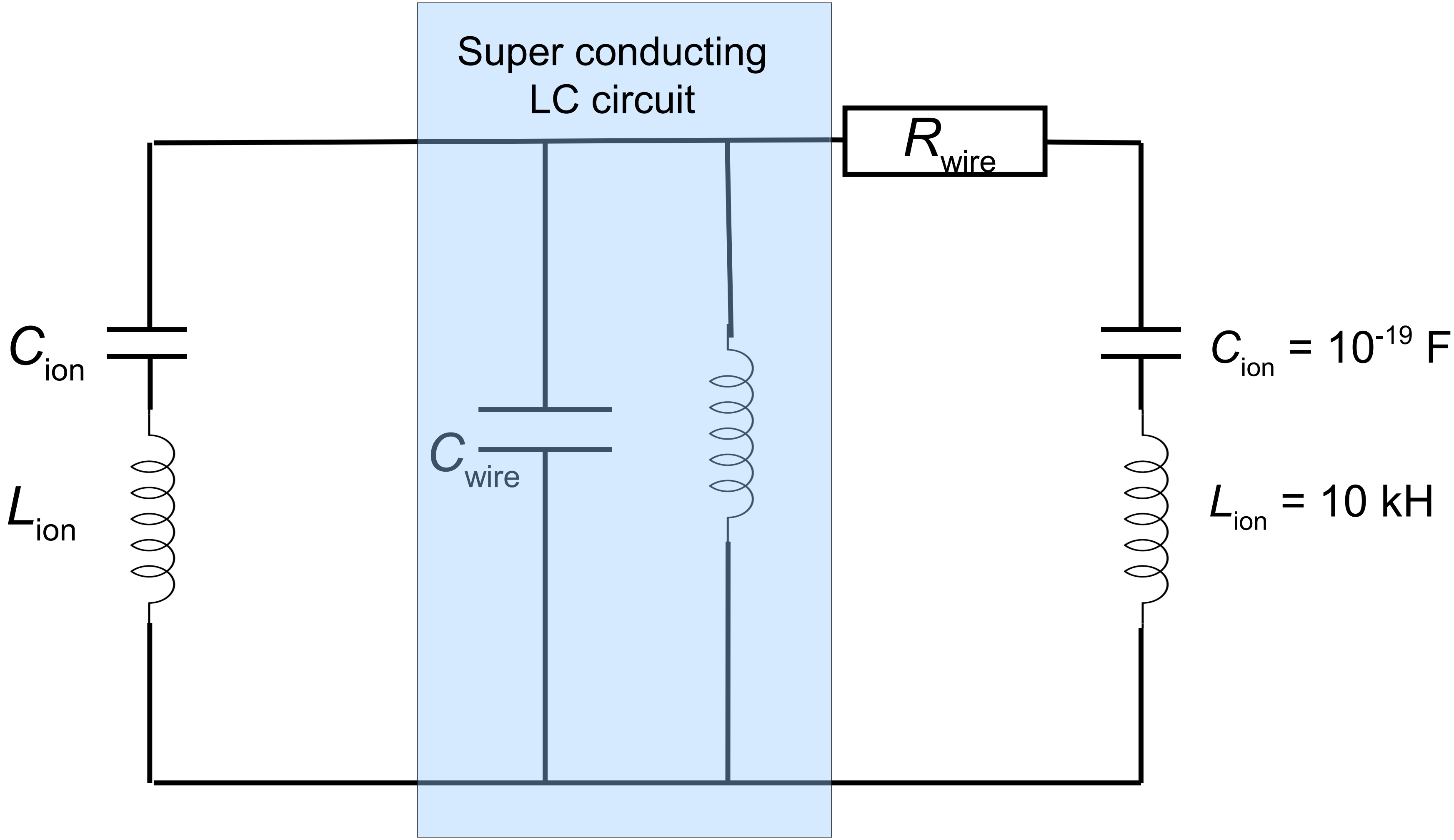
Enhancing the coupling



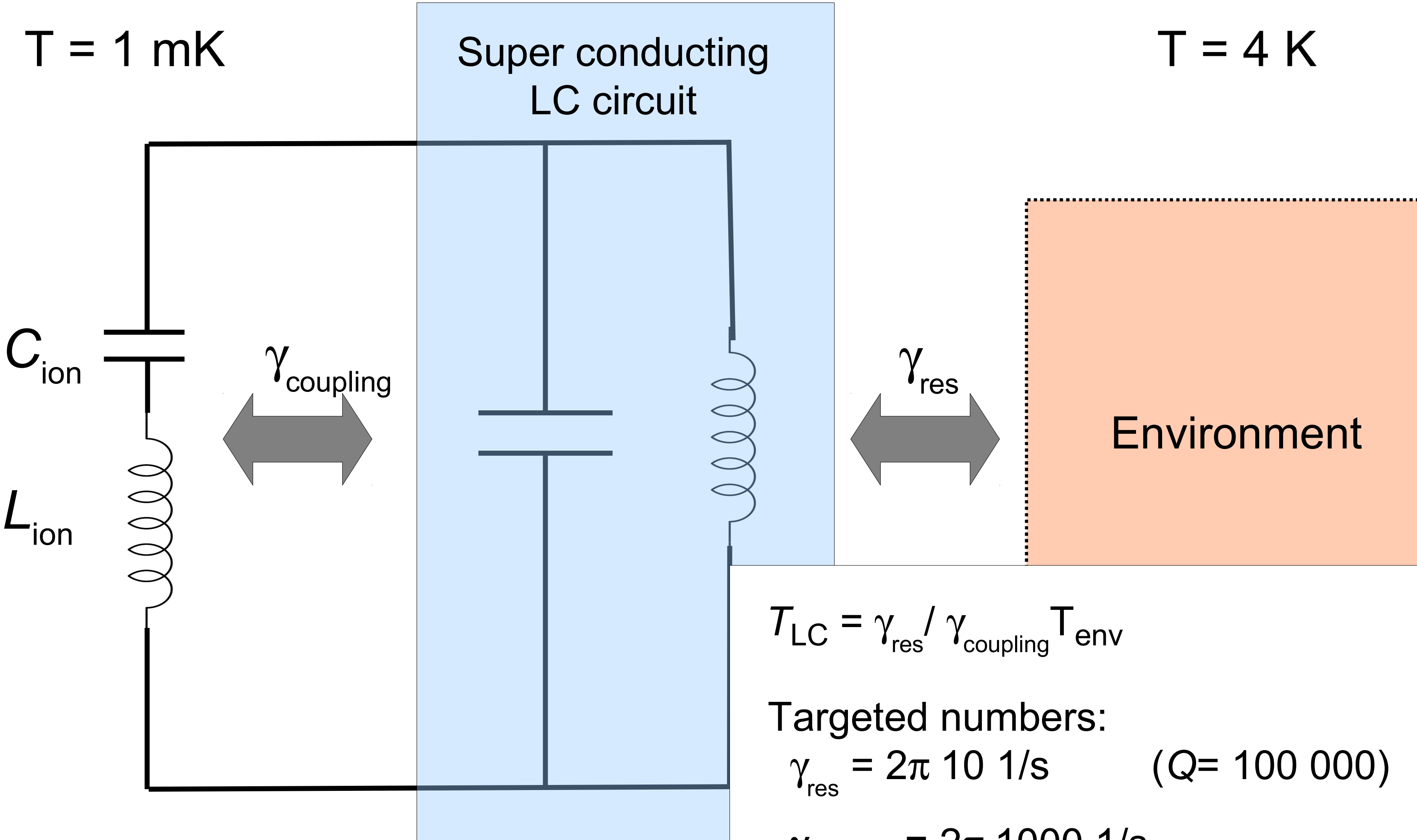
Ion has an impedance > 10^{12} Ω !

Enhancing the coupling



Ion has an impedance > 10^{12} Ω !

Laser cooling a resonator mode



$T_{LC} = \gamma_{res} / \gamma_{coupling} T_{env}$

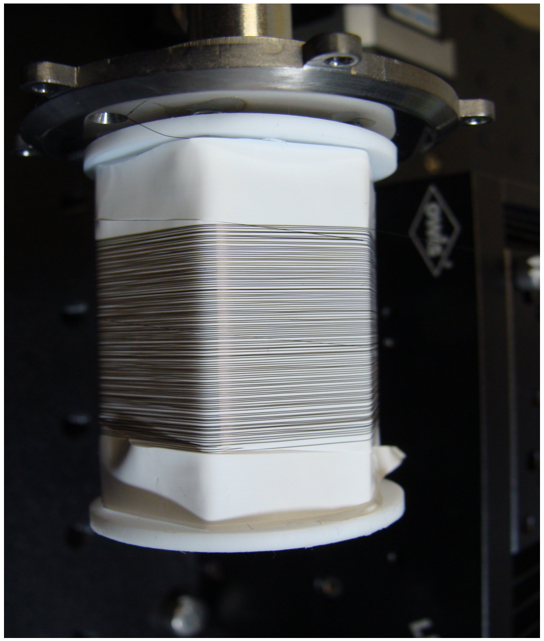
Targeted numbers:

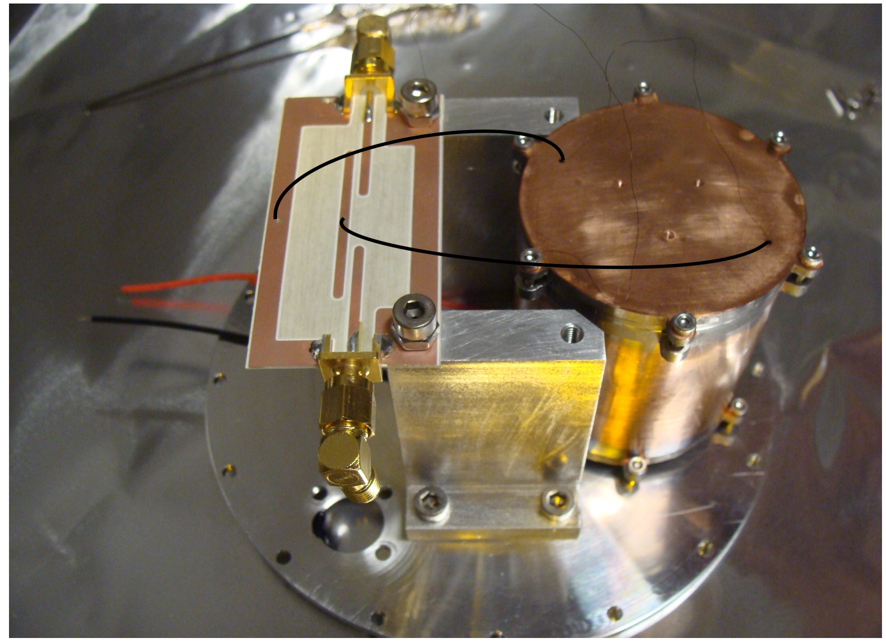
$\gamma_{res} = 2\pi\ 10\ 1/s$ (Q= 100 000)

$\gamma_{coupling} = 2\pi\ 1000\ 1/s$

=> two orders of magnitude cooling

First coil



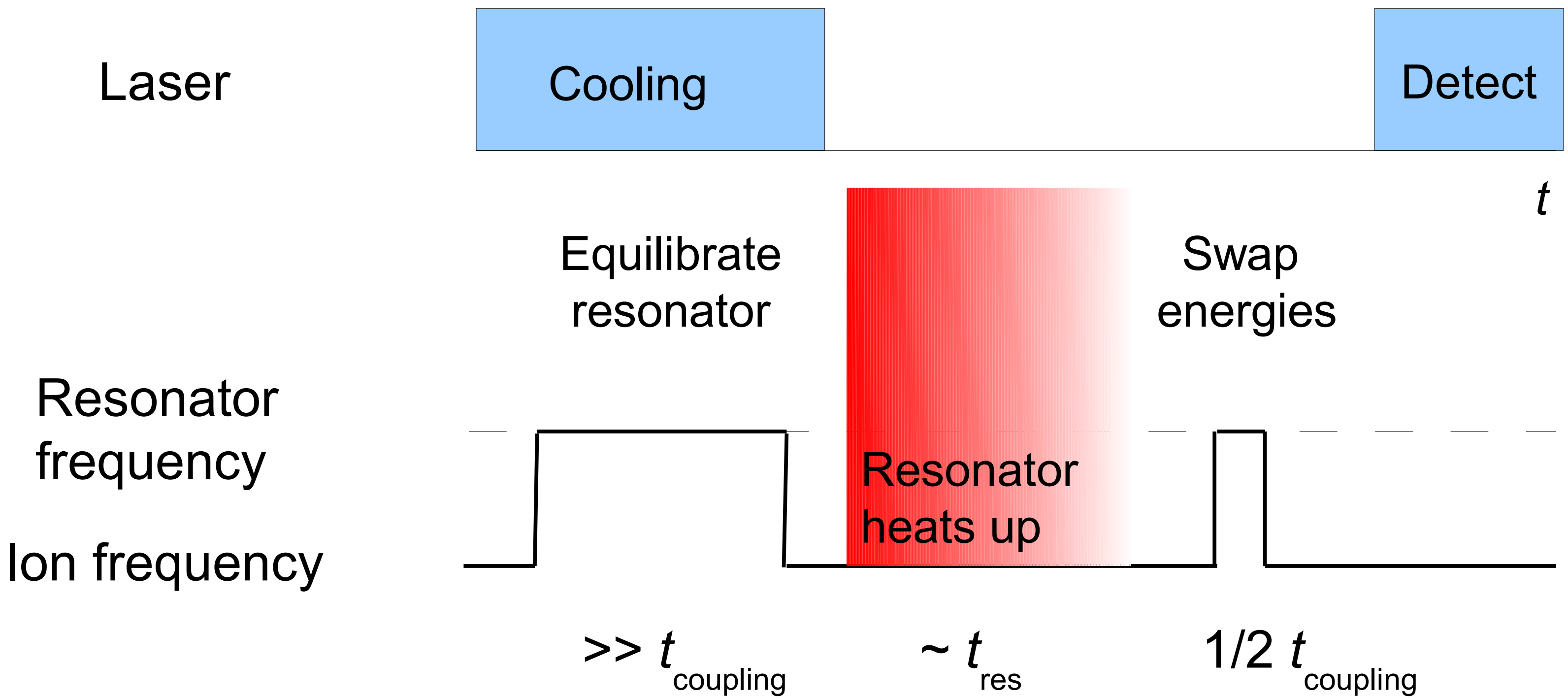


L = 1 mH
C = 2 pF
f = 1.7 MHz
Q = 14 000

$\gamma_{res}/\gamma_{coupling} = 30$

100-ion string
50 μm from surface

Experimental procedure



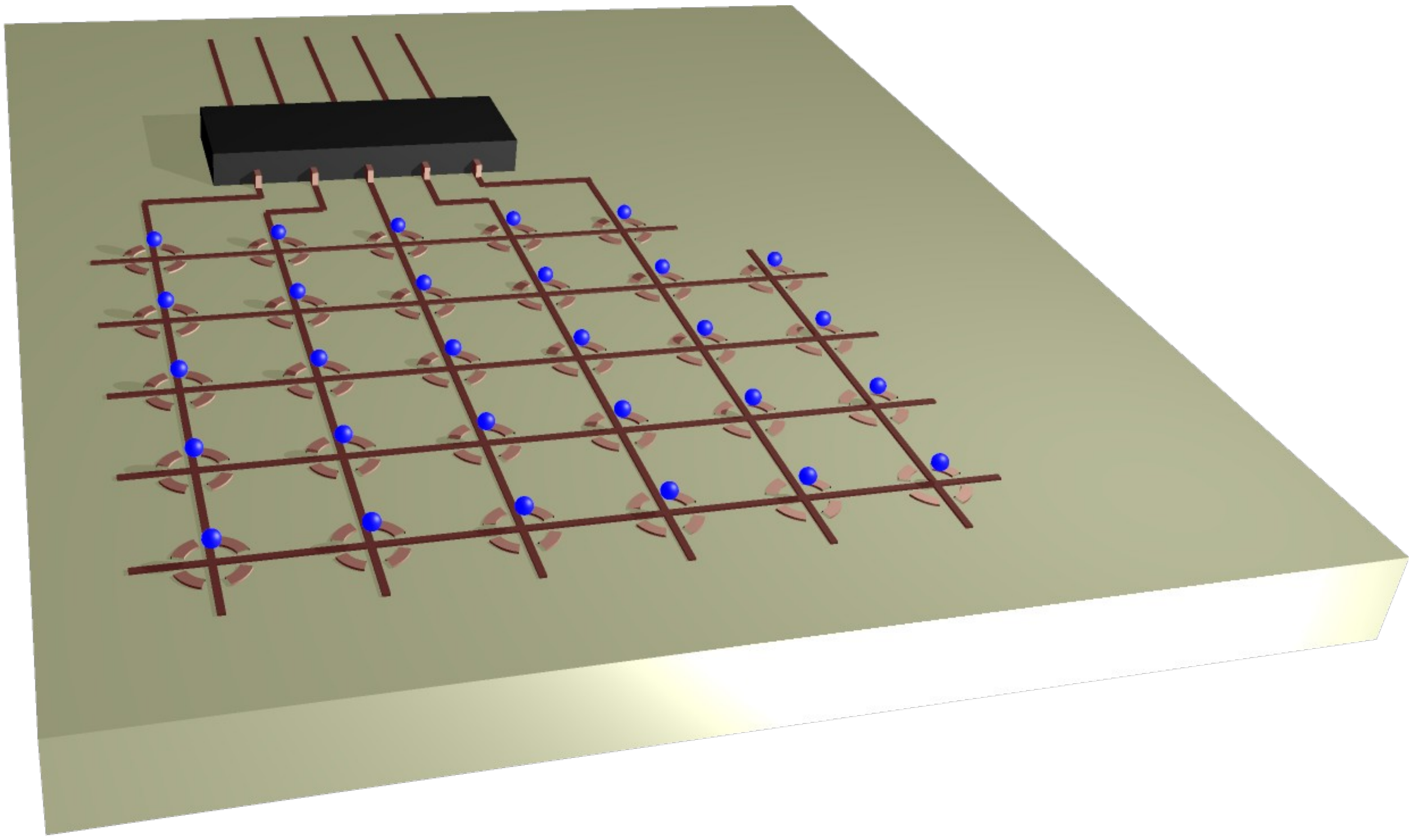
Some perspectives

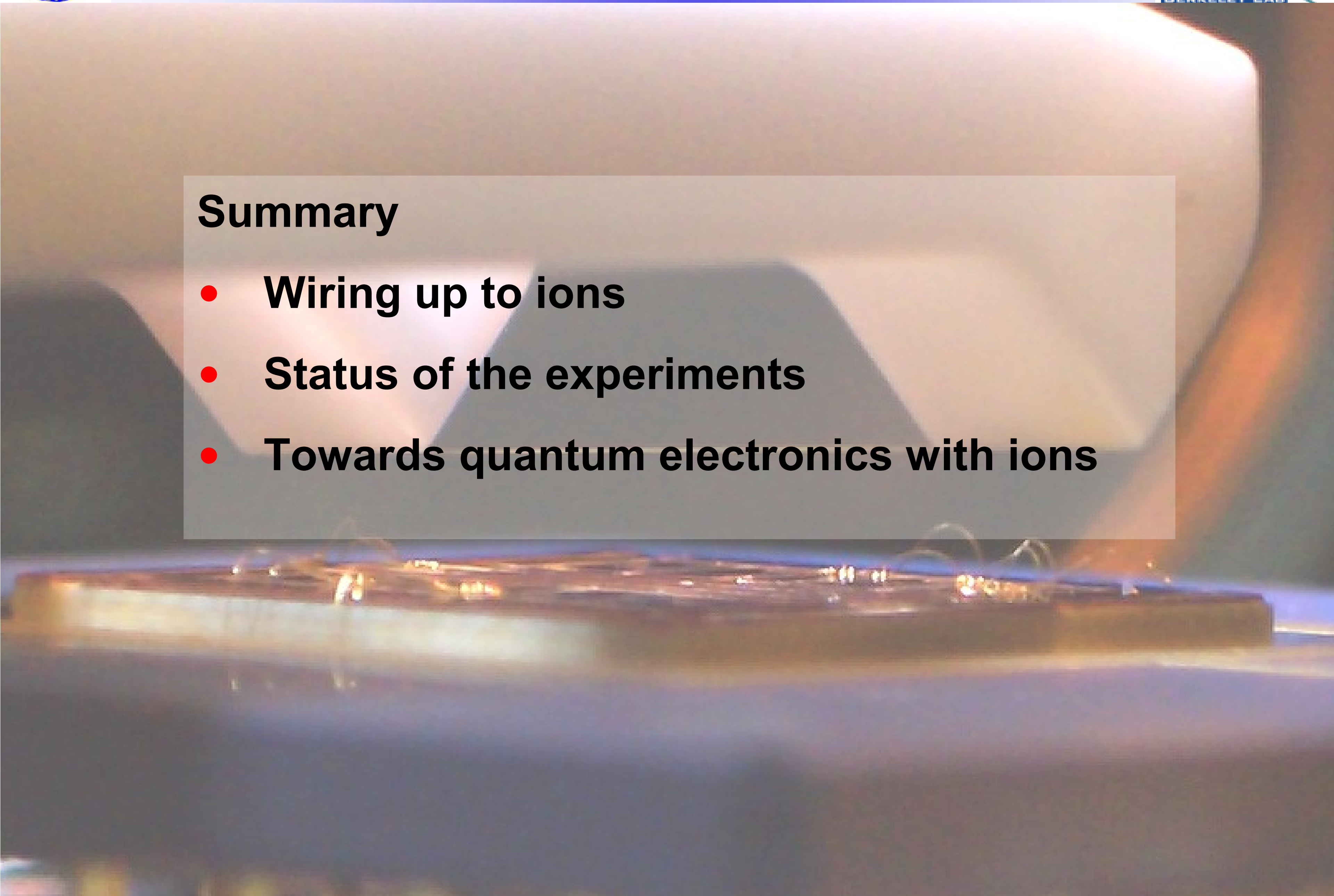
- Push Q limit of MHz resonators

- Couple to Josephson junction circuits

- Sense electromagnetic noise in electrical circuit

A vision





Summary

- Wiring up to ions
- Status of the experiments
- Towards quantum electronics with ions

People

- Greg Bolloton
- Nikos Daniliidis
- Dylan Gorman
- Sebastian Gerber
- Sönke Möller
- Sankara Narayanan
- Oliver Neitzke
- Thaned (Hong) Pruttivarasin
- Michael Ramm
- Ishan Talukdar