Characterization of surface ion trap structures for quantum information processing

Susan Clark, Boyan Tabakov †, Craig R. Clark, Ray Haltli, Jon Sterk, Chris Tigges, Peter Maunz, Matthew Blain, Daniel Stick

Sandia National Laboratories, PO Box 5800 MS 1082, Albuquerque, NM 87185-1082

† Center for Quantum Information and Control, University of New Mexico, MSC 07–4220, Albuquerque, NM 87131-0001

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Abstract

Scaling trapped ion quantum information processing to large numbers of qubits relies on micro-fabricated traps optimized for the applications in quantum computing and quantum simulation.

High trap frequencies and excellent optical access are the key features necessary for quantum information processing that are realized in Sandia's bowtie shaped High Optical Access trap.

For quantum simulations long equidistant chains of ions, and ring-shaped crystals are of interest. Here, we demonstrate a chain of approximately 350 ions in a highly symmetric ring trap.

High Optical Access 1 (HOA1)

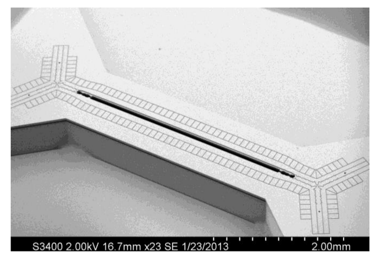
Segmented surface electrode traps need to be compatible with current quantum computing schemes using trapped ions.

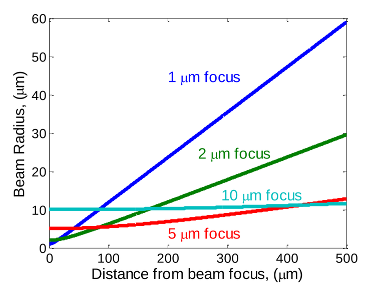
We need:

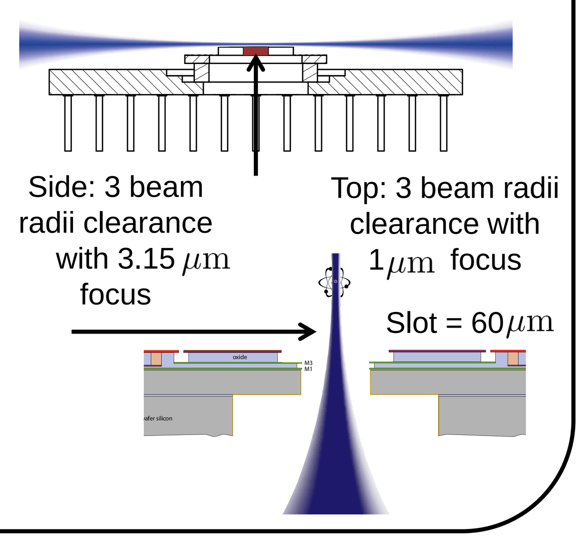
1) Optical access without scattering on the surface of the trap
2) Good micromotion compensation
3) Low heating rates
4) High secular frequencies

Optical Access Without Laser Scatter: HOA 1

Gaussian Optics: more tightly focused beams diverge faster







Some effects of scatter:

1) Interferes with sensitive detection
2) Can create charges and modify trap electric fields

Access from side and top for tightly focused beams

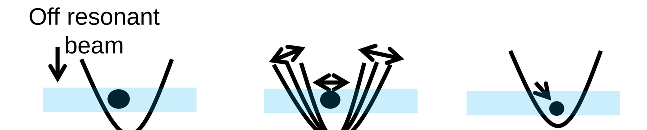
Side: 3 beam radii clearance with 3.15 μm focus

Top: 3 beam radii clearance with $1 \mu m$ focus

Slot = 60μm

Micromotion Compensation

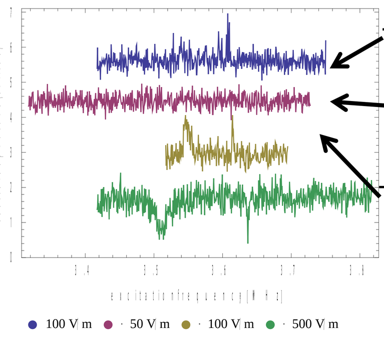
Rf Tickle Technique:



Ion not at rf null

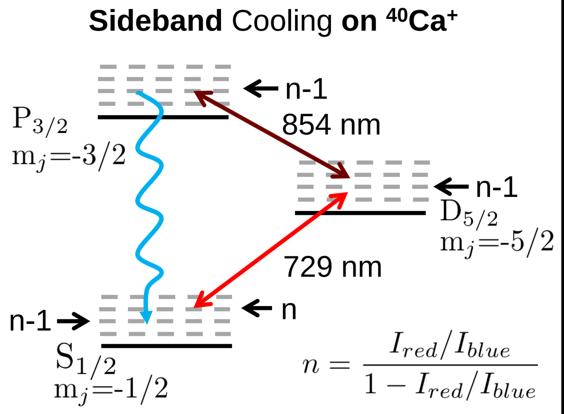
"Shake" the rf potential by trap frequency; shakes ion; ion emits more photons as doppler shift brings it to resonance

Adjust electric fields to minimize scatter, moving ion to rf null



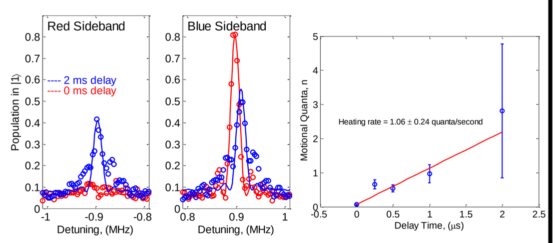
Heating Rate Measurements

Sideband Cooling on $^{40}Ca^+$



$$n = \frac{I_{red}/I_{blue}}{1 - I_{red}/I_{blue}}$$

Blue Sideband, Red Sideband Heating Rate

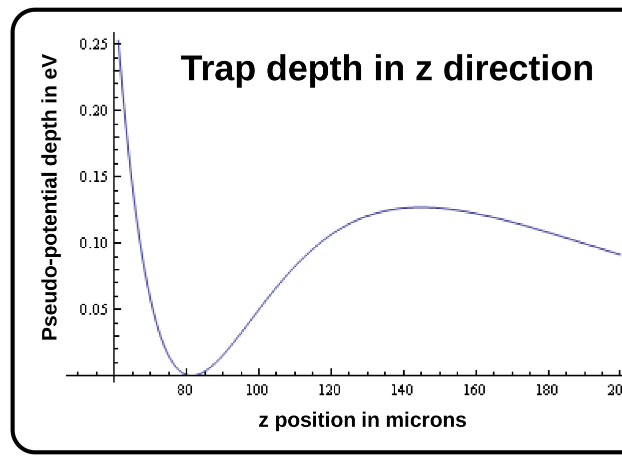


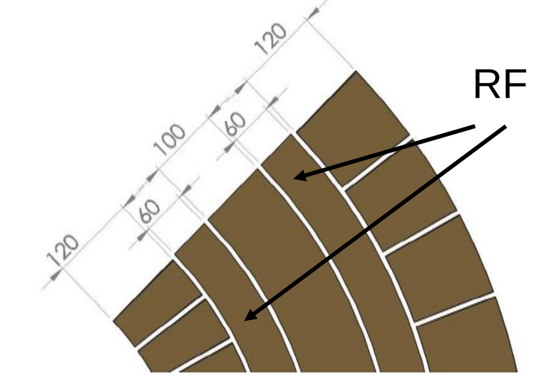
(if not, more details of how heating rate measurements are generally done)

Ring Trap

Motivation

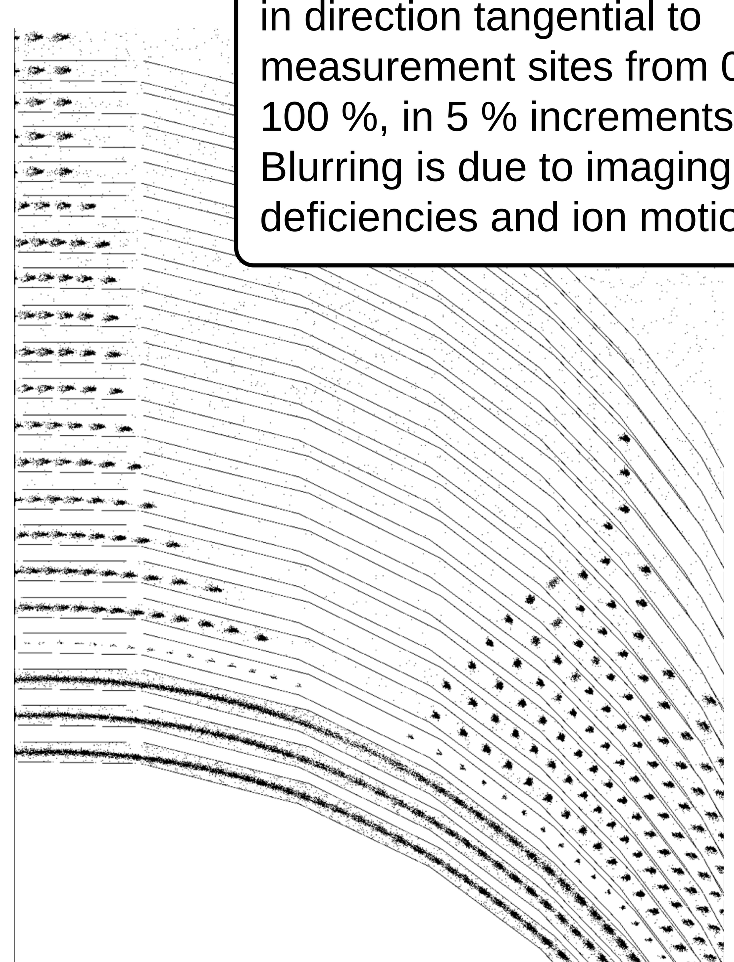
- Large equidistant ion crystal
- RF potential is sufficient to trap ion chain
- Periodic boundary conditions
- Possible applications:
  - phase transitions (E. Shimshoni, G. Morigi, and S. Fishman, DOI: 10.1103/PhysRevLett.106.010401)
  - acoustic black holes (B. Horstmann, B. Reznik, S. Fagnocchi, and J. I. Cirac, DOI: 10.1103/PhysRevLett.104.250403)



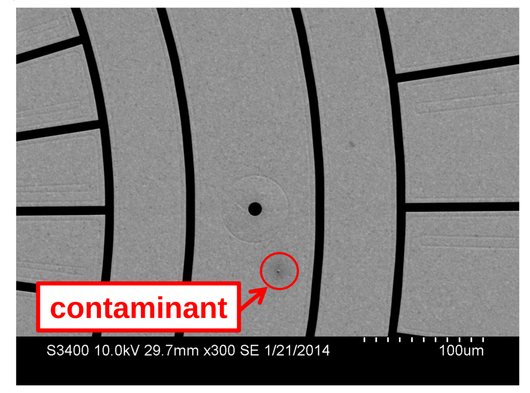


Design and implementation

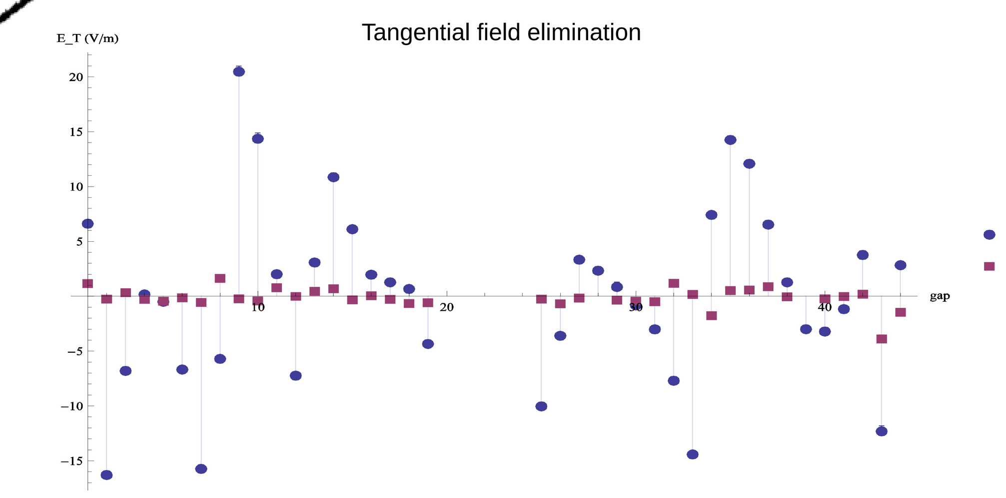
- Relies on 4 metal level fabrication
- Numerical simulations for different species
- RF drive 53 MHz, 150 Vpp
- DC voltages < 10 V
- 624 micron ring radius
- 89 control electrodes
- 10μm loading hole
- For 200 Ca^+ ions ~125 kHz axial confinement (20 μm spacing) without DC
- In vacuum low pass filters
- PEEK ZIF socket

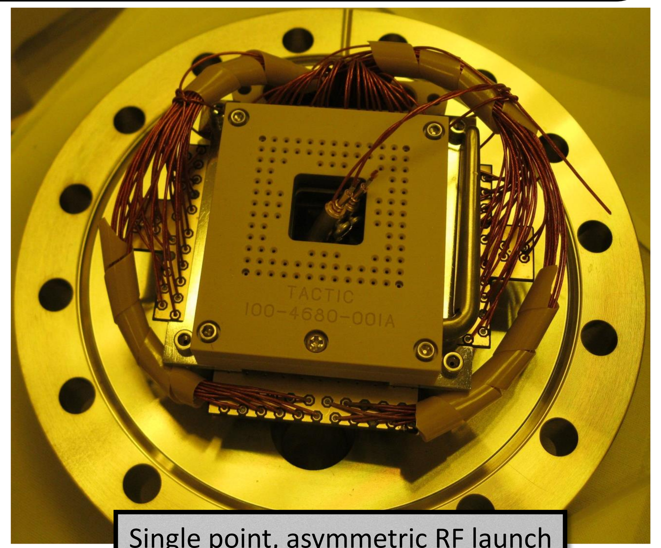


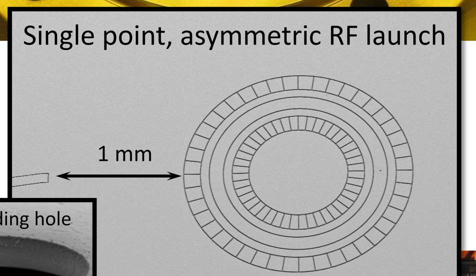
Scaling a correction for fields in direction tangential to measurement sites from 0 to 100 %, in 5 % increments. Blurring is due to imaging deficiencies and ion motion.

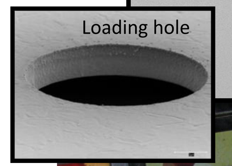


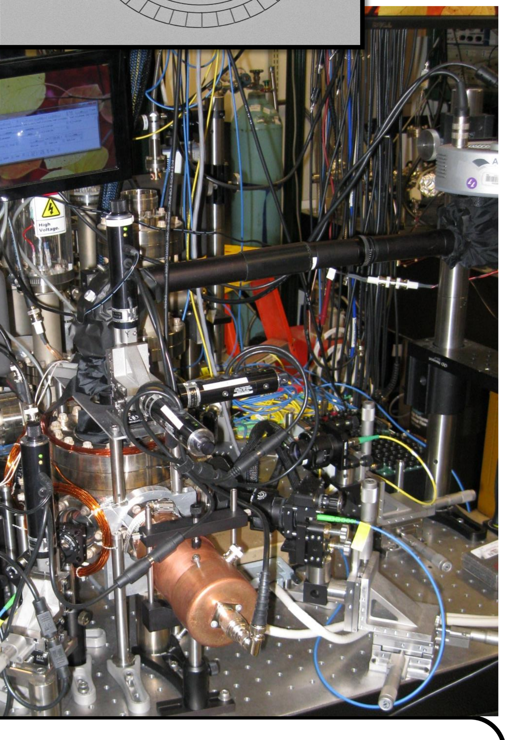
Realizing a long cyclic Ion crystal







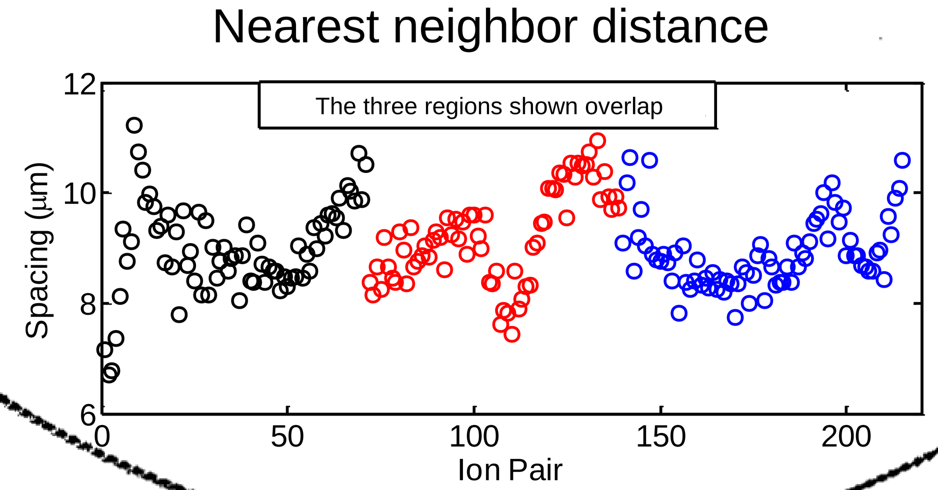




Stray field elimination procedure

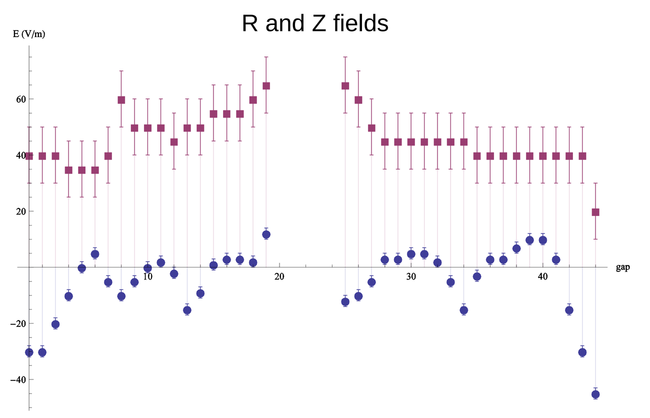
- Tangential fields only are considered at 39 sites
- An electrode producing field in the relevant direction (as seen from simulation) is assigned to each site.
- That field, however, has effect over the full trapping volume and is accounted for at each site
- The electrodes are given weight so that the total field produced (as simulated) cancels the measured field in the tangential direction at each site
- Tangential fields are re-measured
- Ion spacing is inferred from images
- Procedure can be extended to all available 89 electrodes to tackle fields in arbitrary directions for a limited number of sites

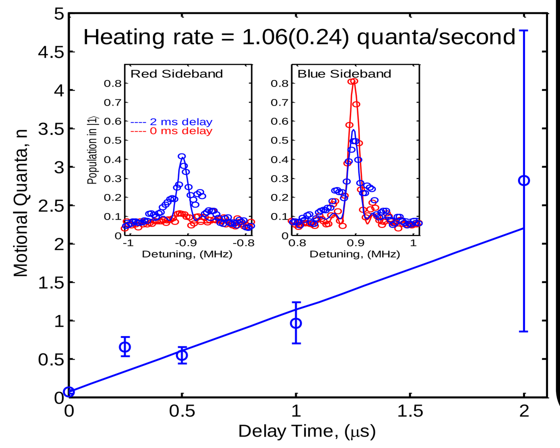
Nearest neighbor distance



Stray field sources and measurement

- Major stray field sources can often be identified as particles contaminating the trap surface
- In addition, long range fields can be inferred
- Fields along 3 directions in the ion frame characterized at 39 locations
- Fields in radial (w.r.t. ion tangential motion) directions assessed with time of arrival and parametric heating techniques
- Fields in tangential directions inferred from ion displacement while scaling a DC trapping solution





Heating rate measurement

- Heating rate is assessed at a site at which stray fields are minimized
- Resolved sideband cooling techniques are used
- Heating rate of 1.06(24) quanta/ms comparable to that of other devices fabricated at SNL

Conclusion

- We demonstrate a proof of principle strategy aimed at producing an equidistant ion chain
- The results can be improved by using all available controls and different stray field compensation strategies

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