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Laser cleaning and background-free detection in microfabricated ion traps

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Laser cleaning of a surface ion trap

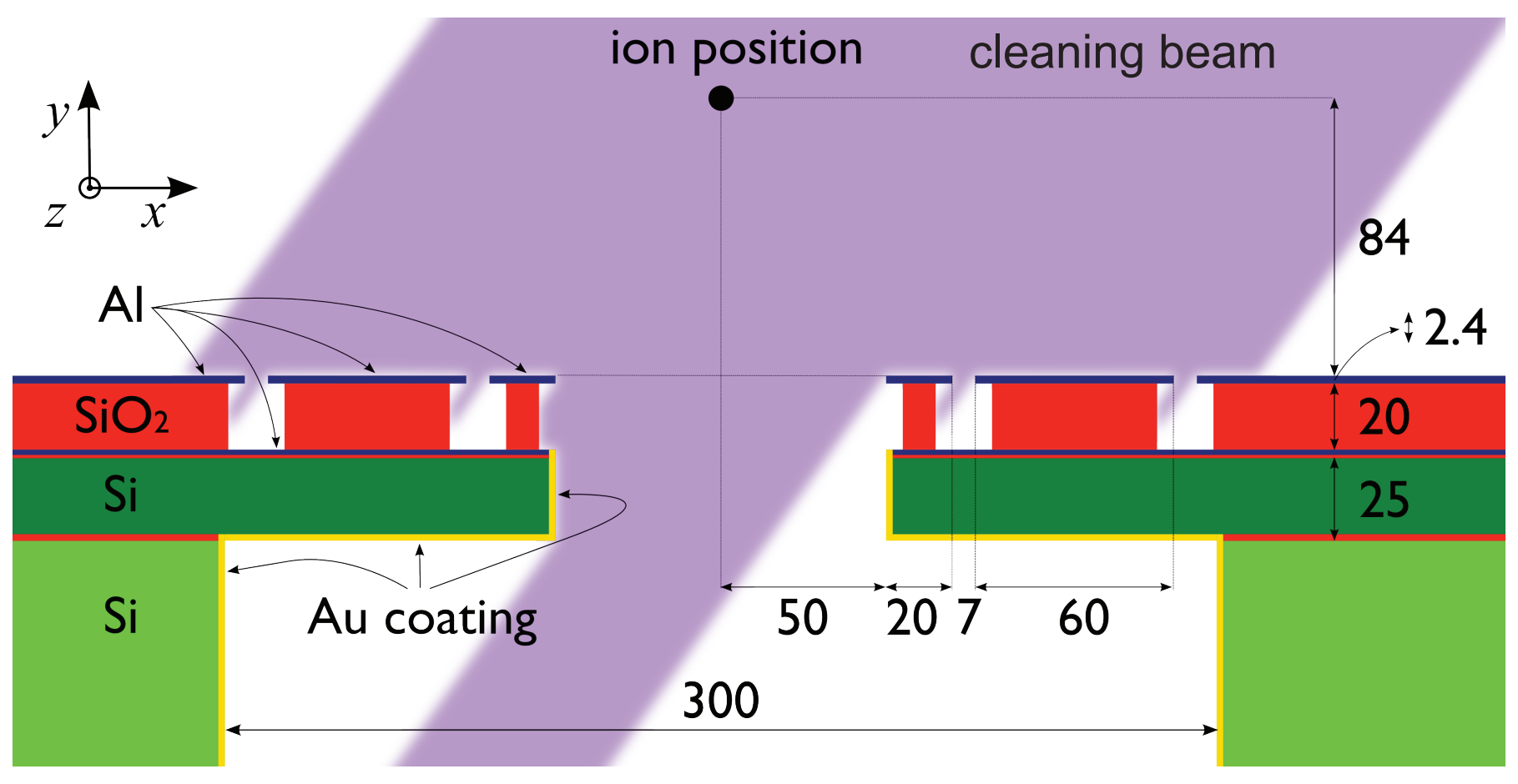
– Allcock et. al. – New J. Phys. 13,123023 (2011)

Outline

Miniaturized structures where laser-cooled ions are trapped at sub-millimetre distances from the electrodes are particularly susceptible to uncontrolled fluctuations of the trap electric fields. These couple to the ion motion and induce 'anomalous heating' which limits the achievable fidelity of multi-ion quantum gates which rely on the motion as a data bus.

A likely cause of this 'anomalous heating' in ion traps are layers of adsorbates on the surface.
We demonstrate that pulsed-laser cleaning of the trap significantly reduces the heating rate (by ~50%).
This was the first reported in-situ reduction of heating rate by removal of the source.

The trap and laser cleaning geometry



The laser used is a 355nm tripled Nd:YAG.
- 2-5ns pulses at 0.2Hz repetition rate
- up to 350mJ/cm^2 in a 300μm diameter spot

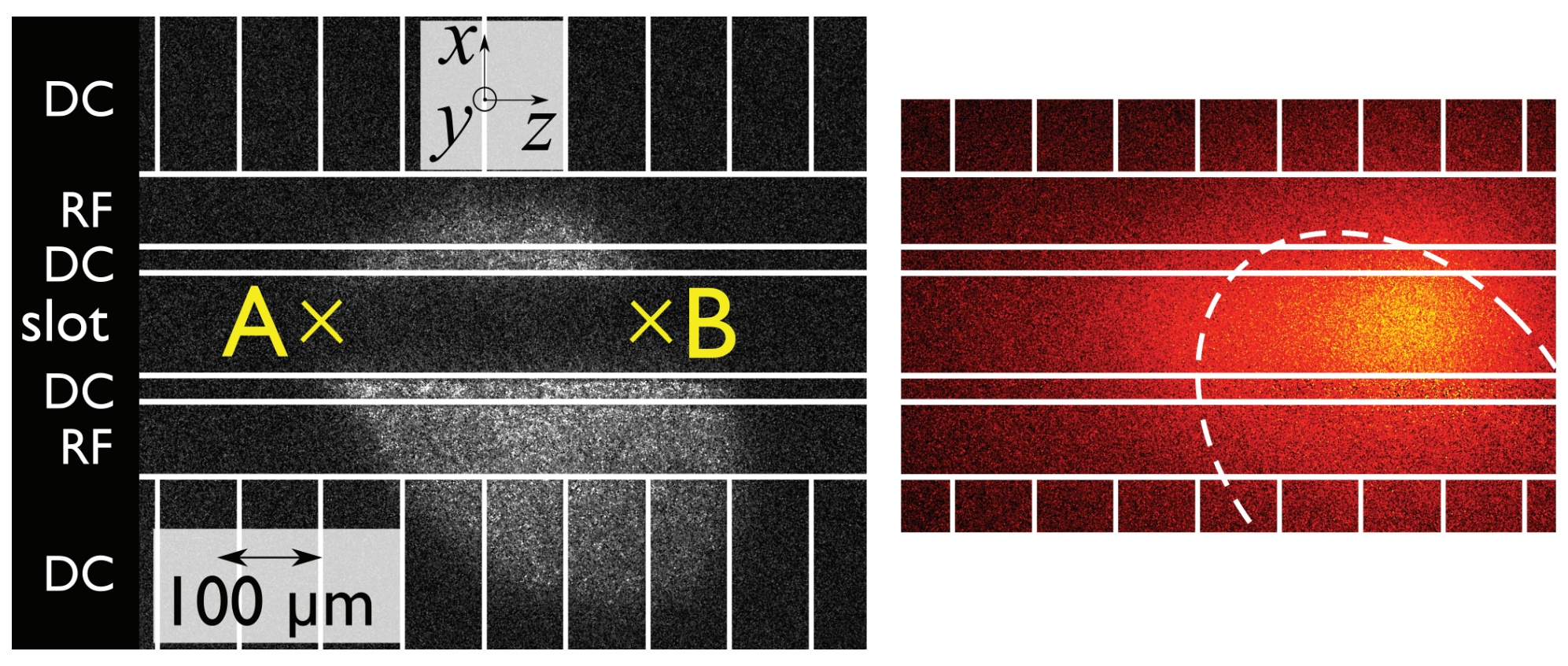
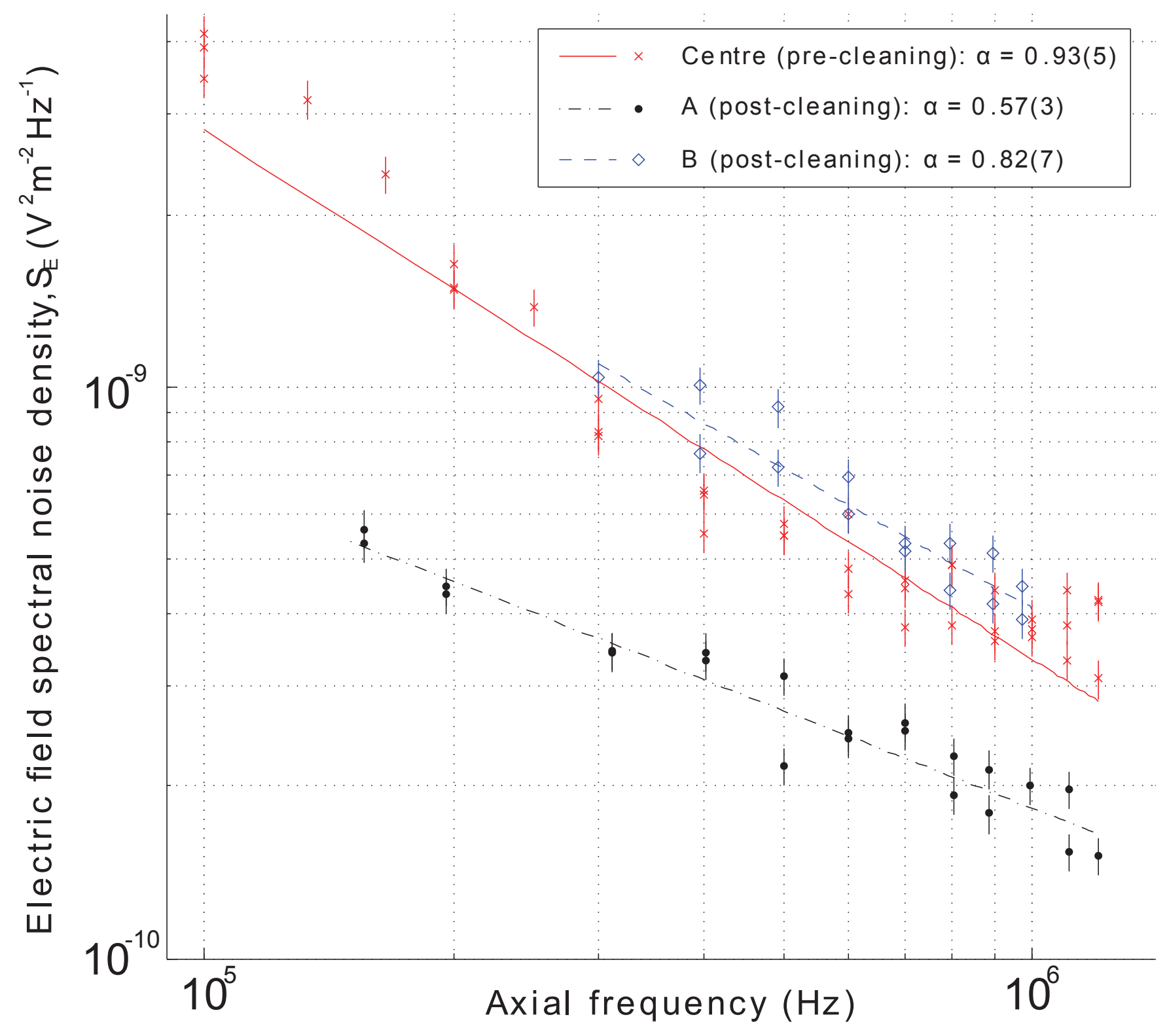


Image of the cleaning spot on the trap (left) and the ablation plume caused when the laser is first applied (right).

Results



The diagram shows a reduction in heating rate of ~50% in the cleaned area (A) compared to uncleaned area (B).

Note also the change in frequency dependence ($\omega^{-\alpha}$) of the spectral noise density S_E.

Outlook

These results are supported by a study of Ar$^+$ bombardment cleaning of trap at NIST (arXiv:1112.5419) which reported two orders of magnitude reduction. Laser cleaning is experimentally advantageous and more flexible however, so further experiments to optimise the technique should be performed.

Background free detection of trapped ions

– Linke et al. – Appl.Phys.B 107, 1175 (2012)

Outline

Background scatter from the cooling beam is a problem for ion detection in microstructured ion traps and experiments where ions are trapped close to surfaces. We present and compare alternative repumping schemes in $^{40}Ca^+$ to demonstrate background free ion detection.
Background is then only limited by the detector dark counts.

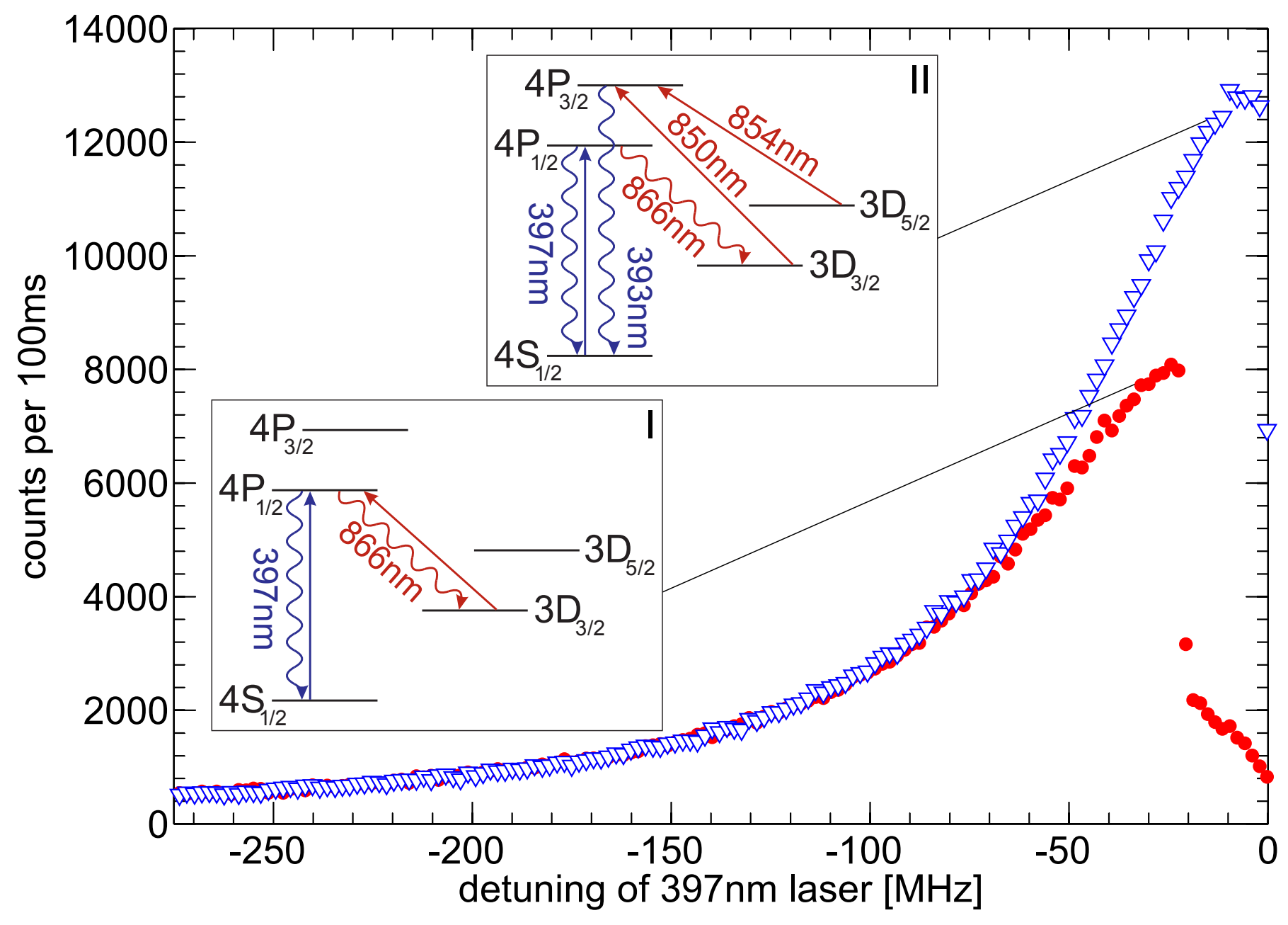
The schemes

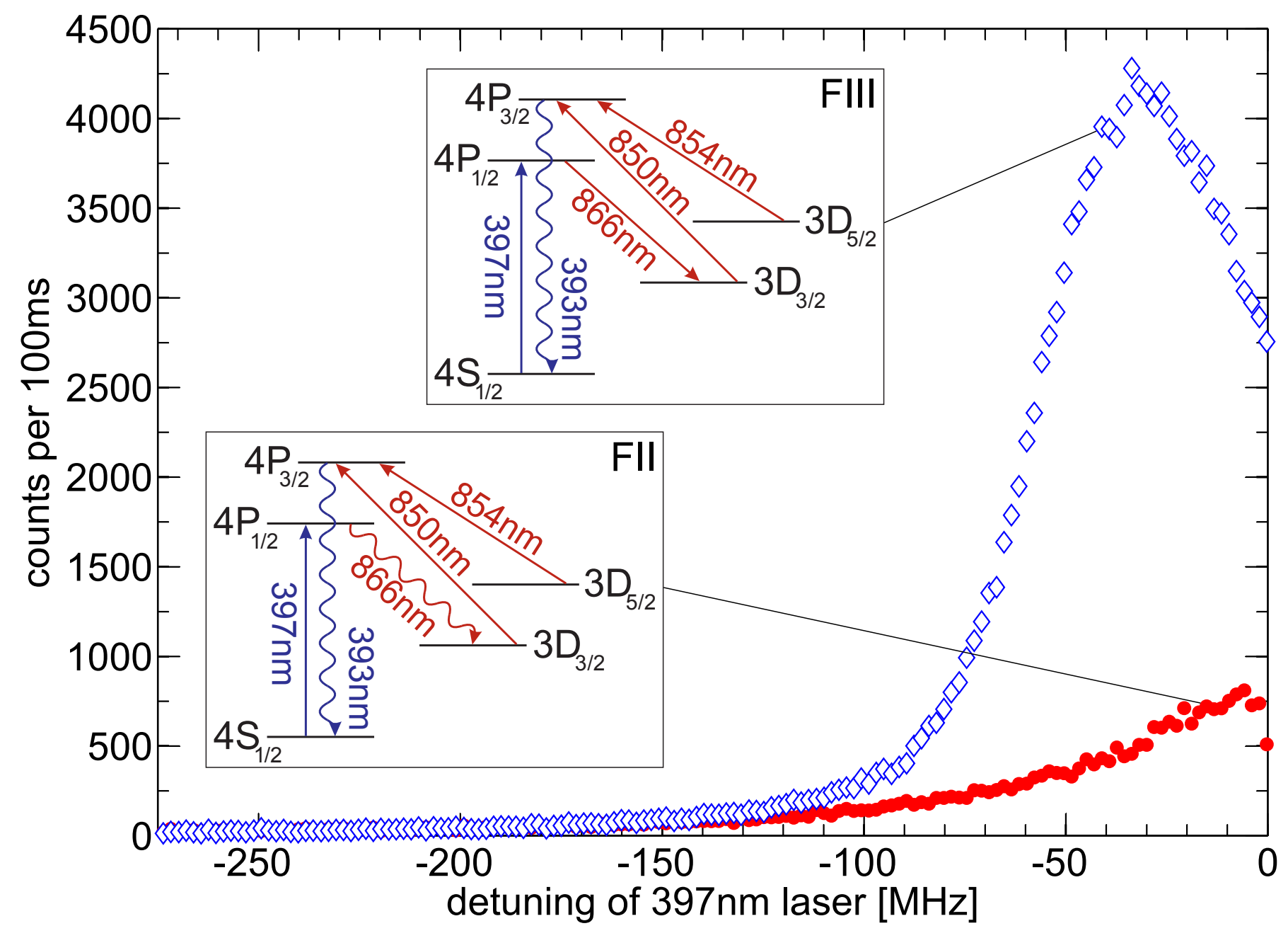
Scheme I (fig. A): Standard Doppler cooling and repumping scheme using 866nm laser. This allows the use of $D_{5/2}$ state as as one of the qubit states or as a shelf for qubit readout. However if qubit readout is not the goal better schemes exist (see below).

Scheme II (fig. A): 850nm and 854nm lasers are used as repumpers. This gives higher photon count and cooling rates and allows easier interpretation of some experiments (e.g. heating rate measurements by Doppler recooling see bottom right) due to lack of 2-photon coherent effects such as dark resonances.

Scheme FII (fig. B): Background-free detection is achieved adding an interference filter in the detection system to block 397nm light and detect only 393nm fluorescence. Only photons coming from the ion are detected.

Scheme FIII (fig. B):The 866nm laser is used in addition to drive population into the $D_{3/2}$ state. This significantly increases the count rate but coherent effects make the choice of parameters important.



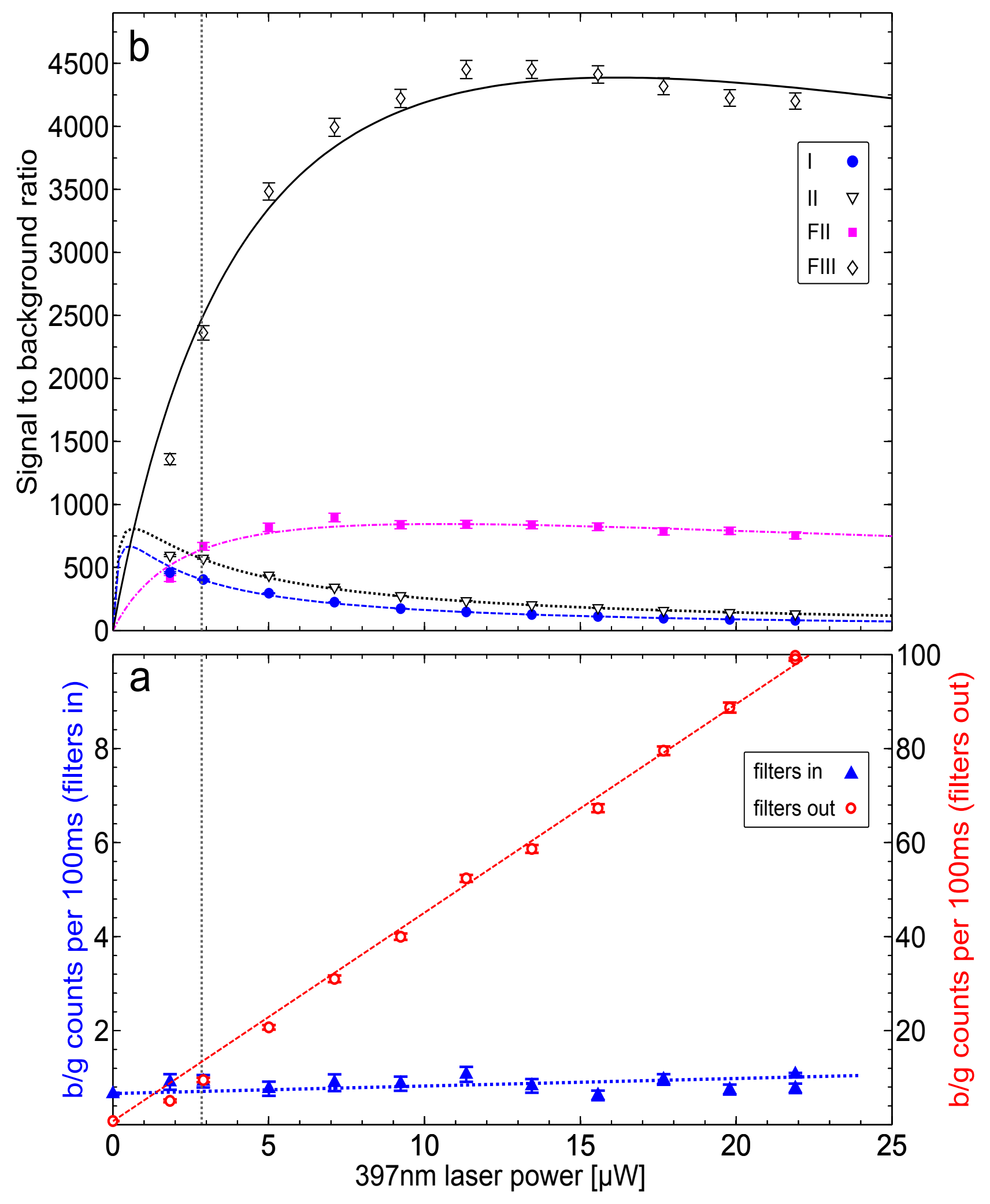


Results

The data on the right show background counts with and without the interference filter (a) as well as a comparison of the signal/background ratios for the four schemes (b).

With moderate saturation of the cooling transition (vertical dotted line), we achieve a fluoresence signal of29000counts/s with only 1count/s of scattered laser light using scheme FIII.

(I_{sat} ~1.5μW)



Outlook

We are performing experiments towards a pulsed method which will allow background-free detection without involving the $D_{5/2}$ shelf state.

Goal: Background-free qubit readout.

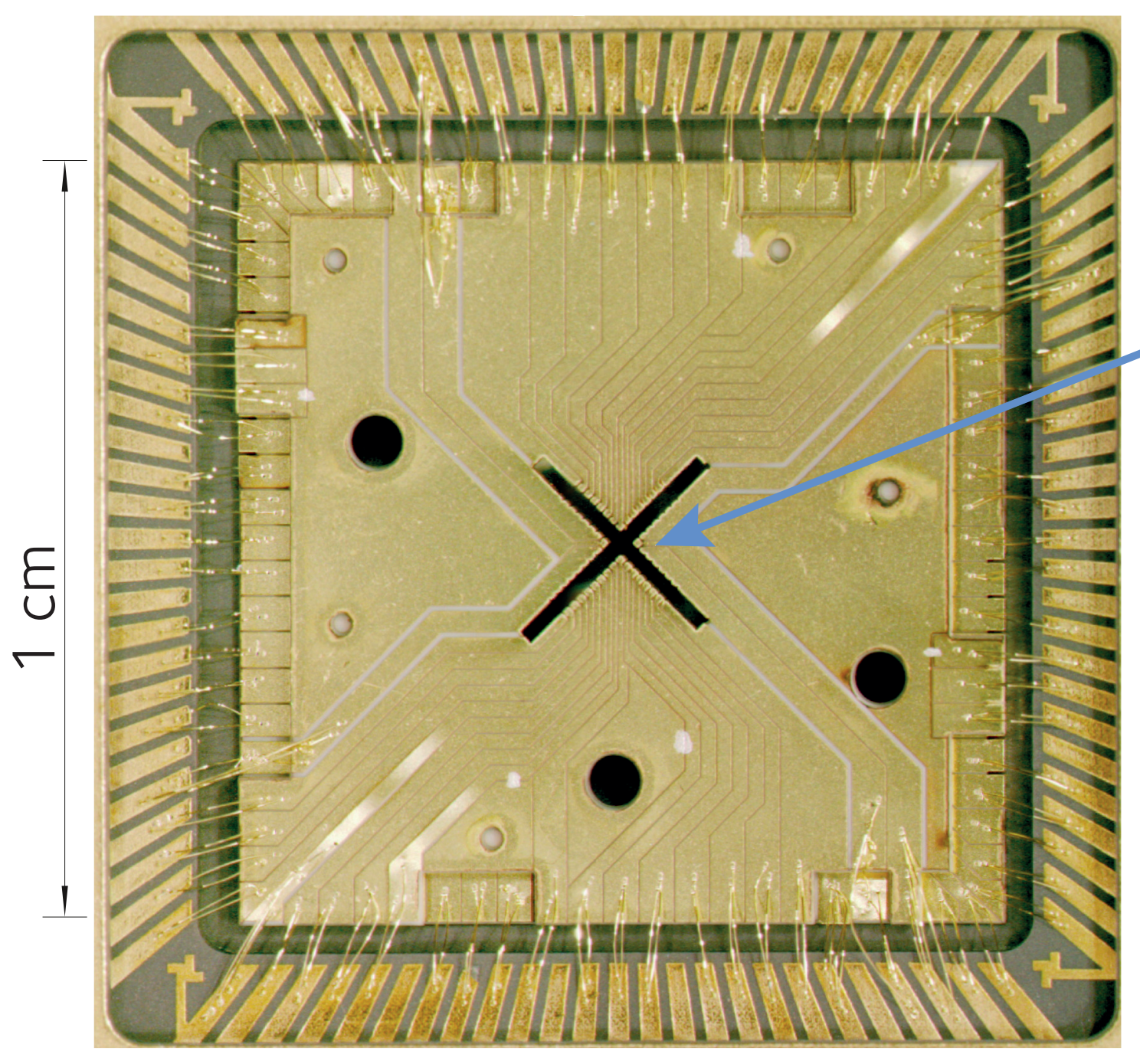
A cross-shaped microfabricated ion-trap

The trap

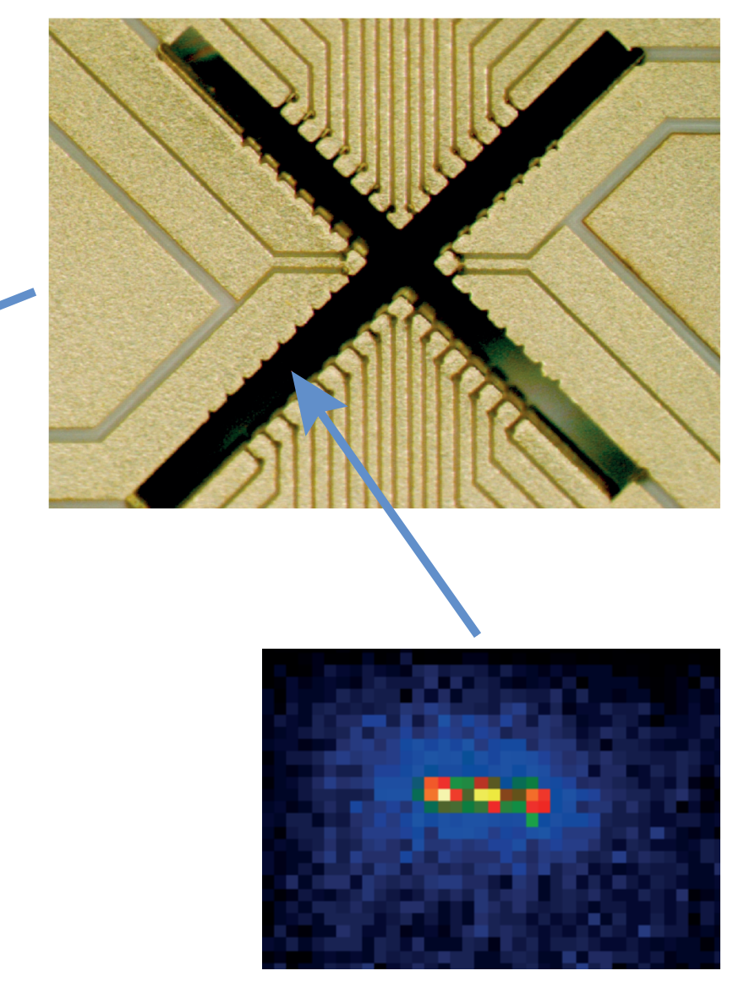
Microfabricated multi-zone traps are a way to make ion trap quantum computing scalable by giving control over several ions.

The trap shown here has four arms each of which is an independent linear Paul trap. They are connected through a central junction.

The trap was designed in the European Microtrap collaboration, manufactured by Micreon and assembled in our group.



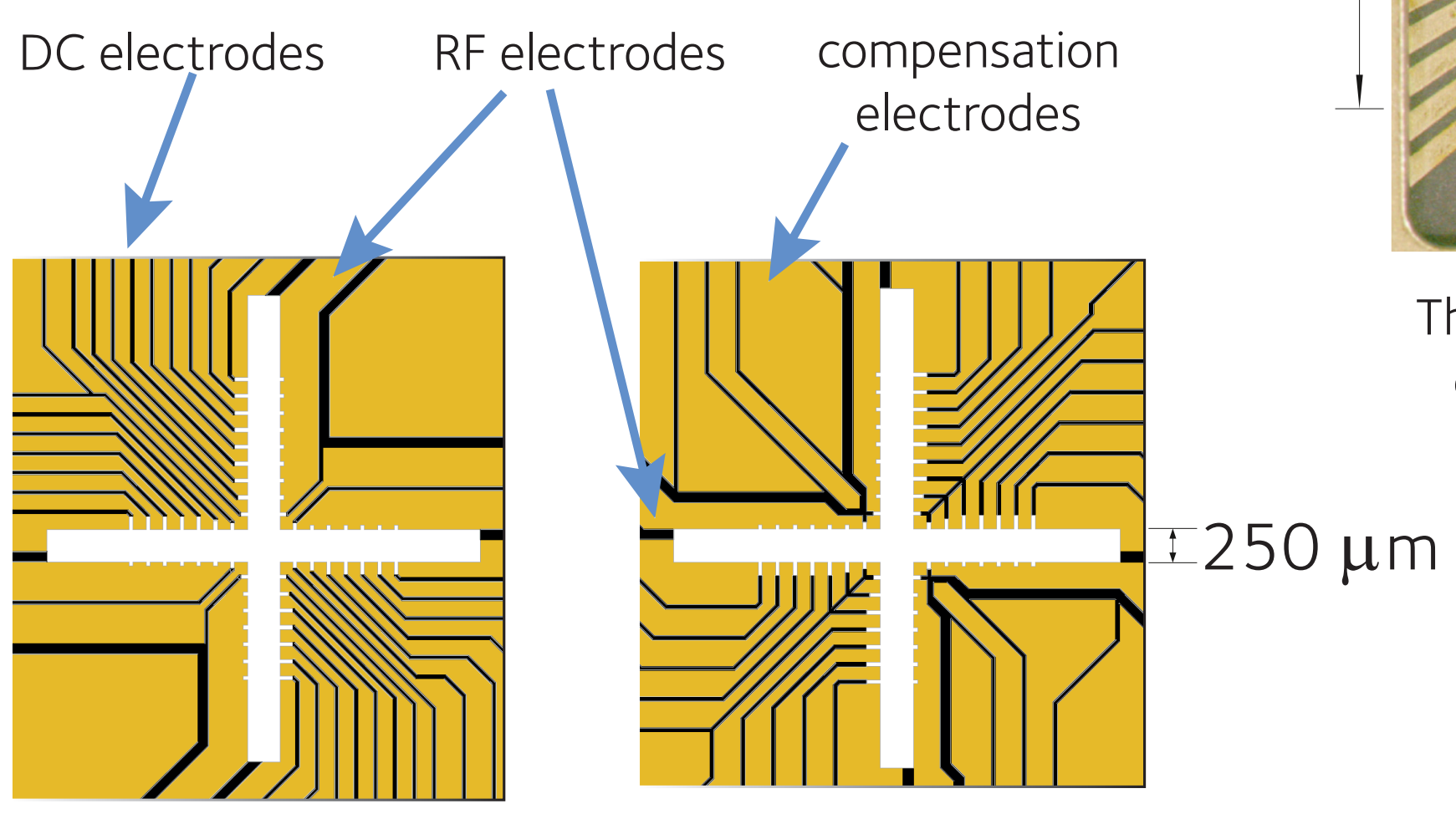
The trap electrodes are bonded to a standard chip carrier (IPKX0F1-8180AB) with a central hole



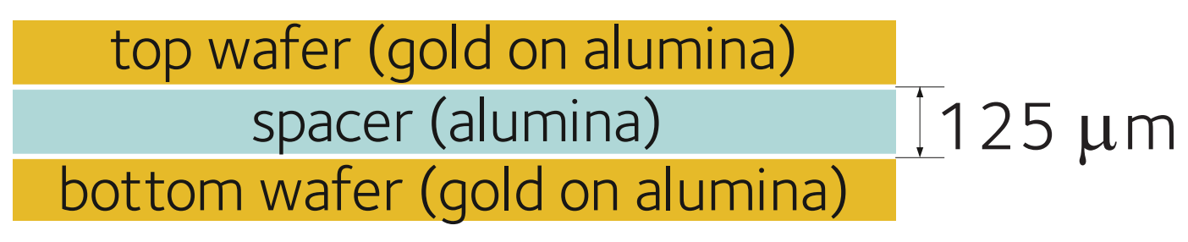
A string of three 40Ca+ ions in the longest trap arm.

The ions are compensated using special electrodes and offsets on the DC electrodes.

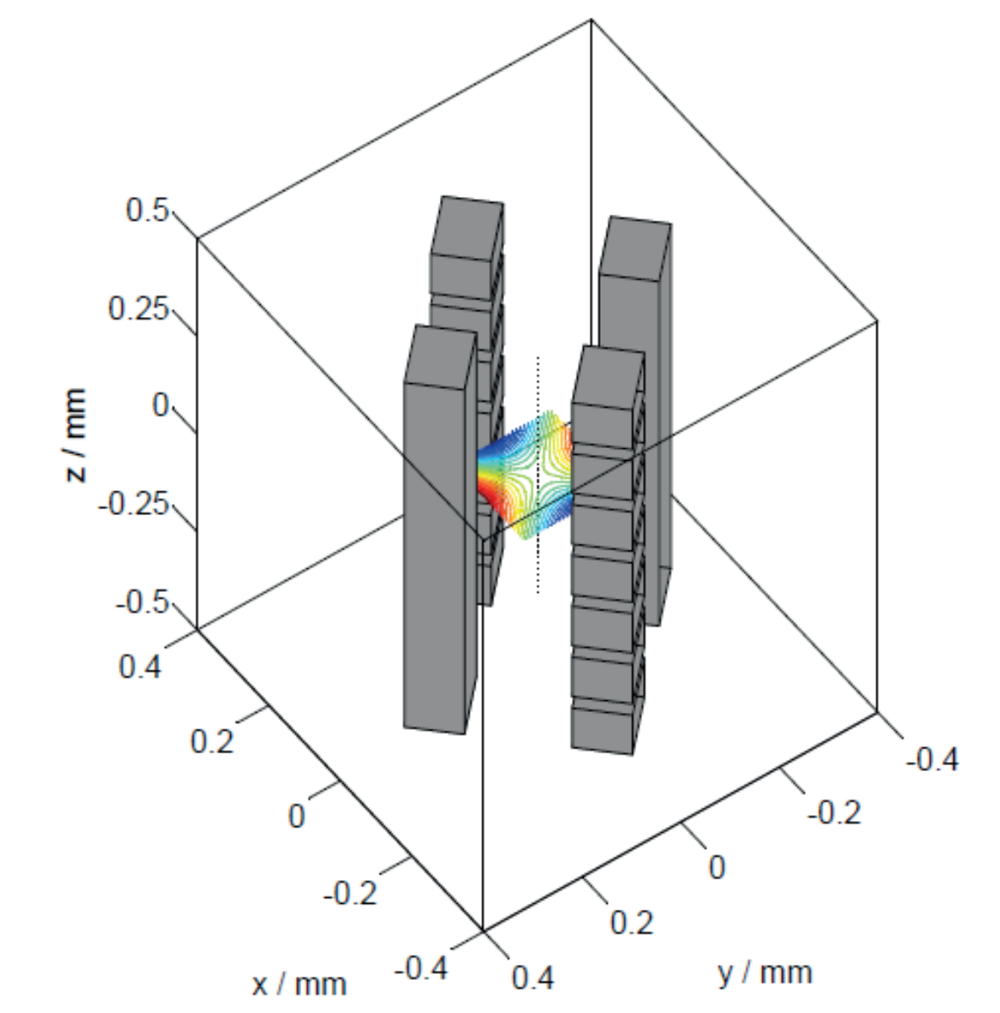
Residual field ~3V/m



The trapping region of the cross-trap with the bottom wafer (left) and the top wafer (right)



Sandwich assembly: The trap layers are held together by heat curing Epoxy

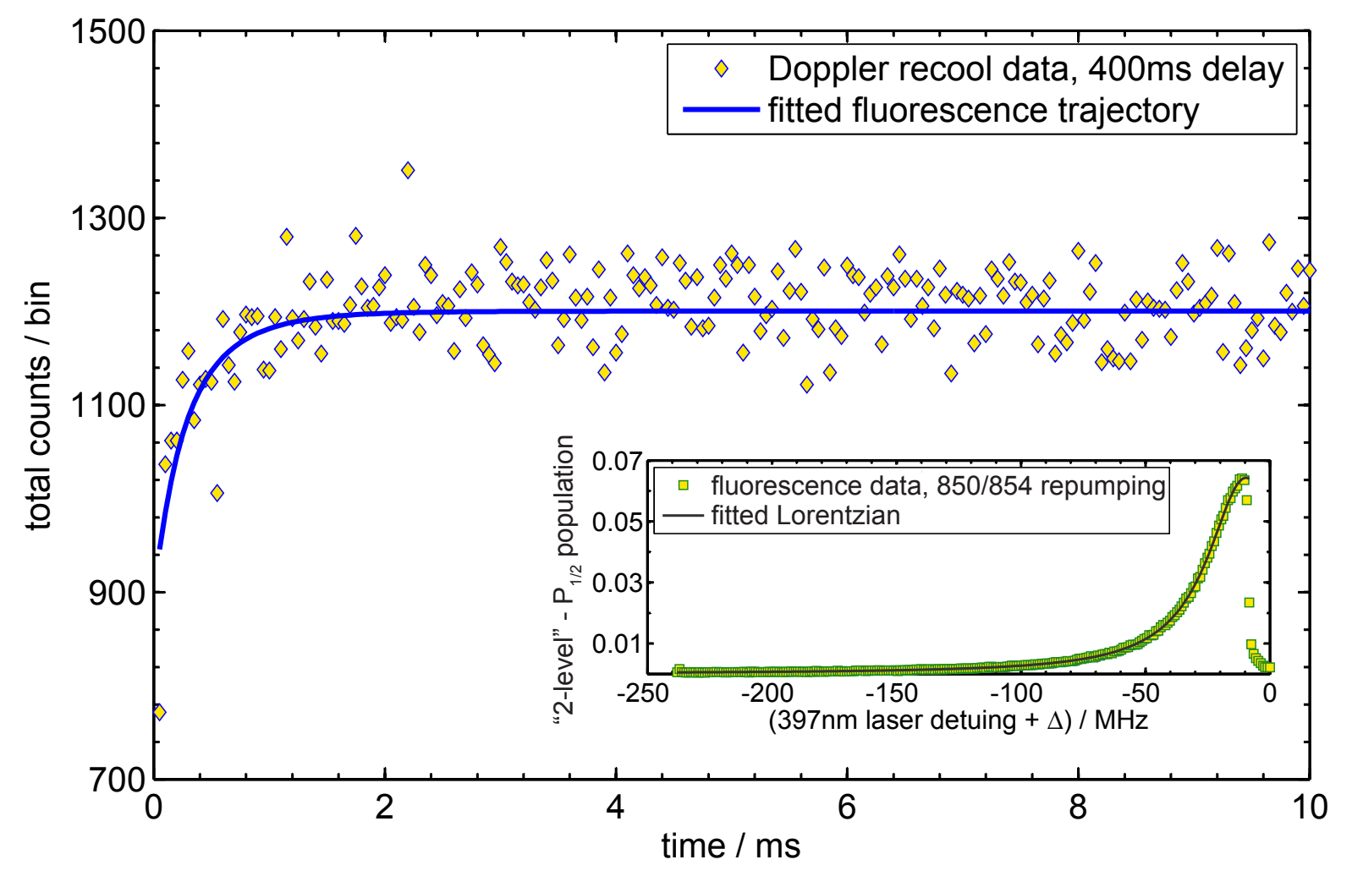


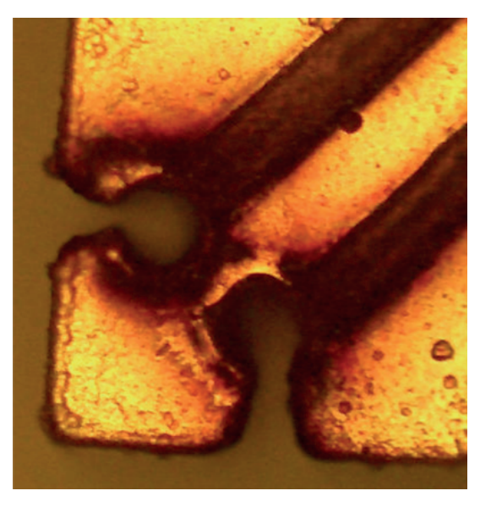
A simplified model of the trap (left) allows potential calculations and will be the basis for transport simulation.

We find agreement with the experiment at the ~10% level.

Heating rate

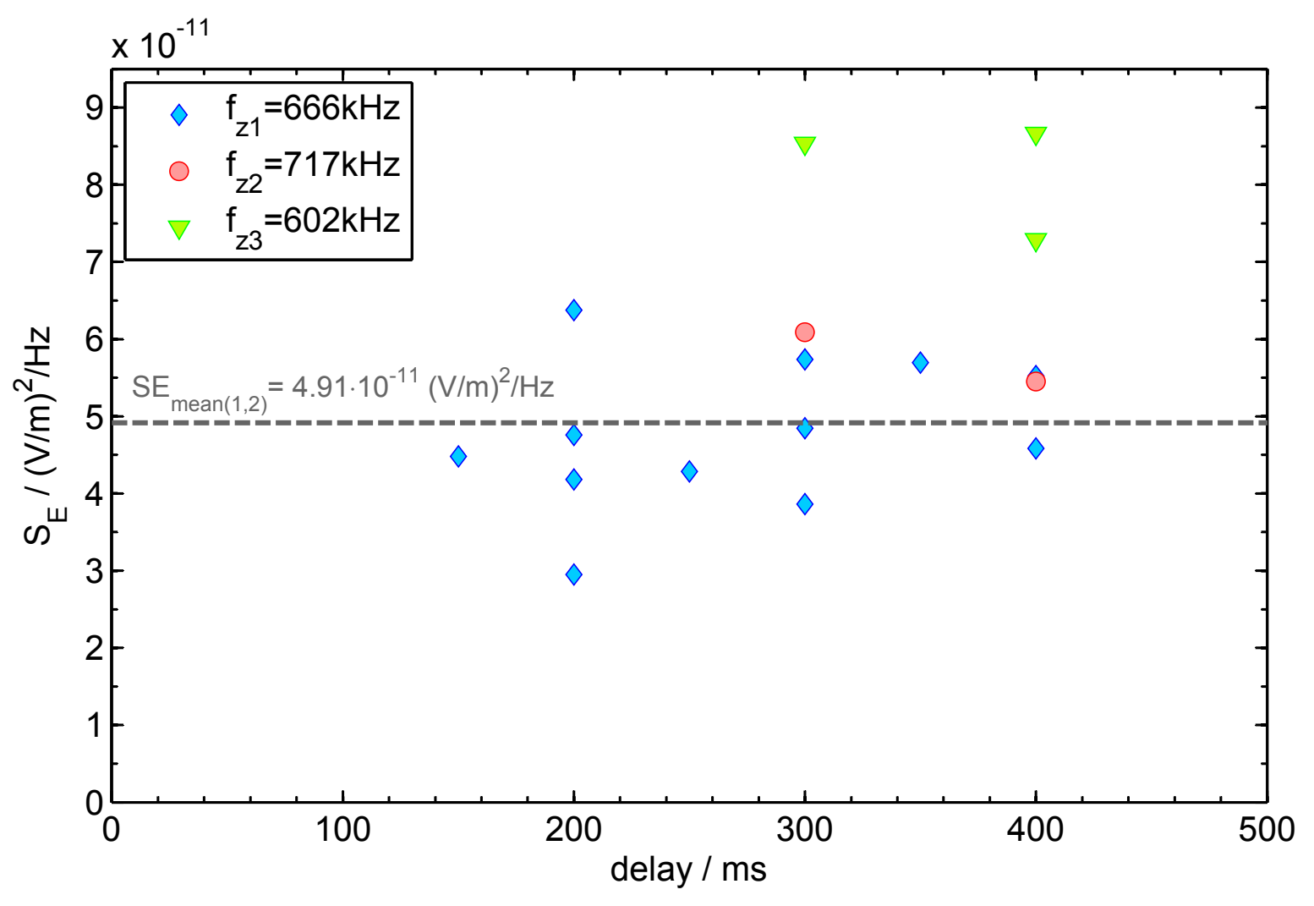
The heating rate was measured using a Doppler-recool method (Wesenberg et al. PRA 76, 2007).
The result is consistent with the Microtrap used in Ulm (Schulz et al. N. J. Phys. 10, 2008), but above average for its ion- to-surface distance (135 μm).





Microscope image highlighting gold layer problems.

Electroplated gold surface has features that can cause field inhomogeneities.
However, the Innsbruck group achieved a lower heating rate with similar gold surface (Harlander et. al., Nature, 471:200, 2011).
Electrode filtering in our trap can be improved by in-vacuum filters.



Outlook

Trapping in other arms, ion shuttling.
Design improvements for junctions, compare NIST paper by R. B Blakestad et al. Phys .Rev. A, 84 (2011).

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EPSRC IOTA Microtrap