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REALISATION OF A LINEAR PAUL TRAP FOR OPTIMAL CONTROL OF QUANTUM GATES WITH TRAPPED IONS

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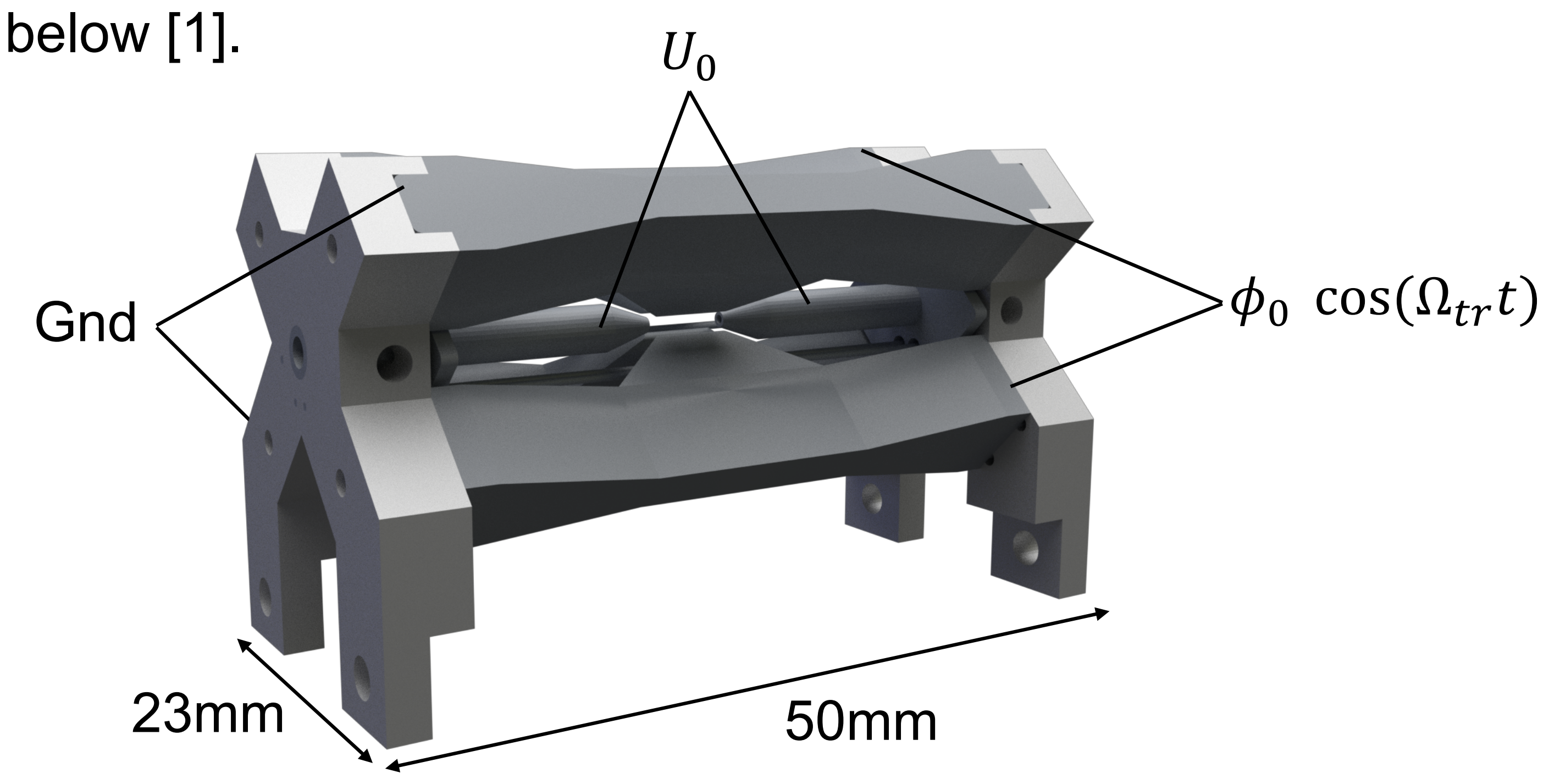
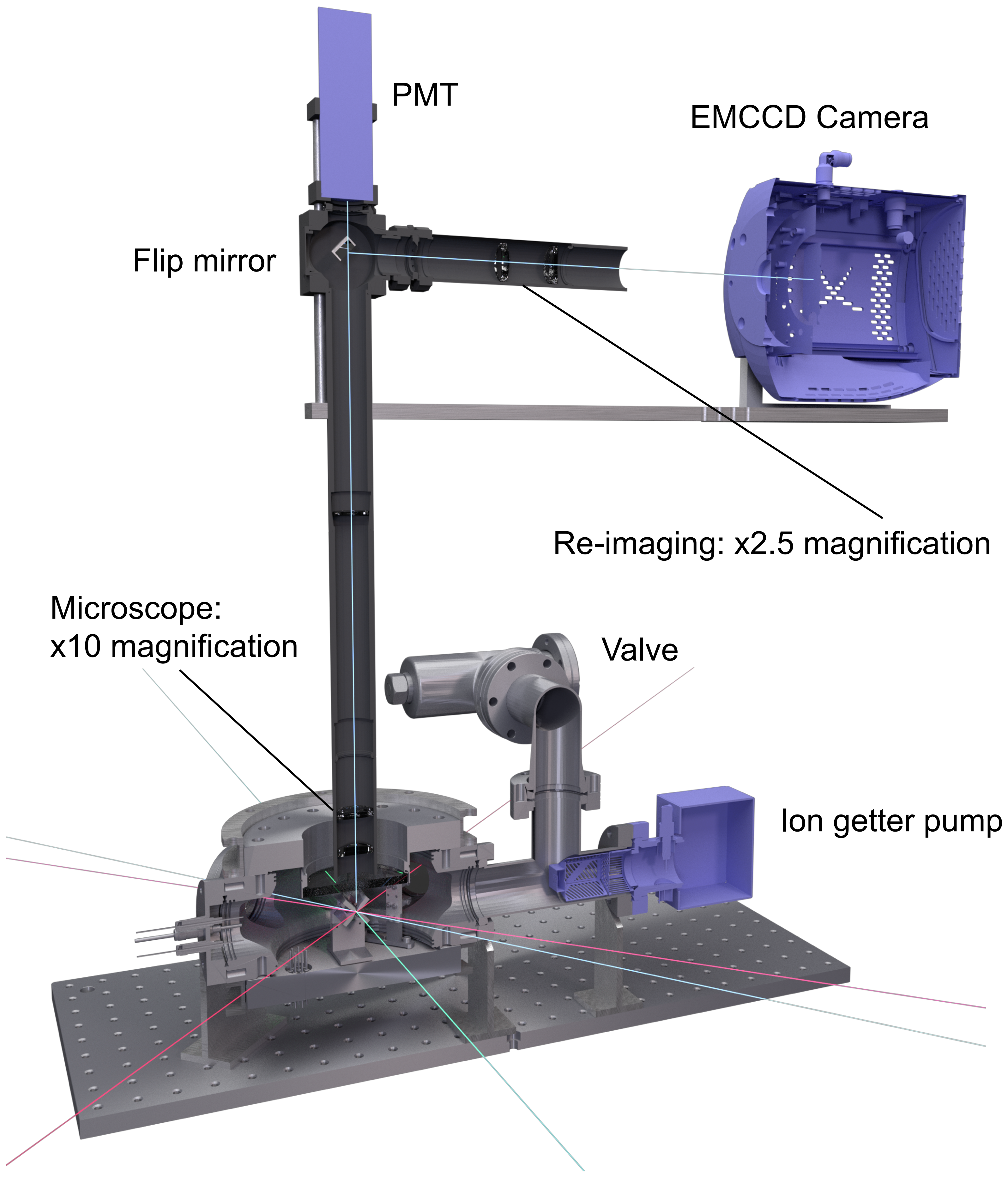
Trapped ions proved to be a promising physical system for the realisation of scalable quantum computers. However, their implementation in quantum information processing is still limited by slow two qubit gates. This work presents the assembly of a linear Paul trap that will be used to implement optimal control techniques for two-qubit gates. Focus is given to the design of the imaging system and the set up of the loading system through photoionisation.

ION CONFINEMENT

The confinement of ions is realised by a pseudo-potential with a minimum at the trap centre. In linear Paul traps, the potential is realised by four and two electrodes for radial and axial confinement respectively. All electrodes have a static potential except for two of the radial electrodes which have an oscillating voltage applied to them as shown below [1].

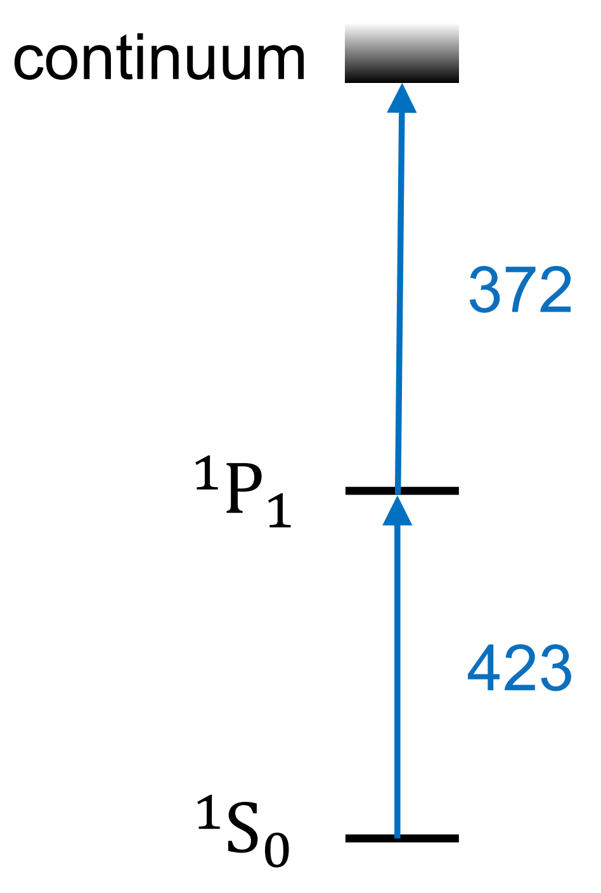


VACUUM CHAMBER AND IMAGING SYSTEM

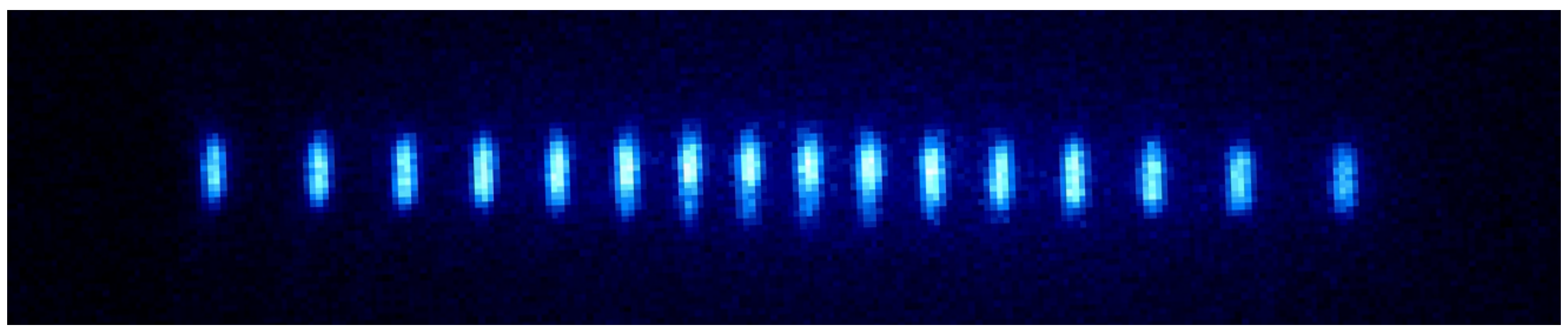


There are six different wavelengths of laser beams involved in this experiment used for laser cooling, state detection, photoionisation and coherent manipulations.

PHOTOIONISATION OF $^{40}\mathrm{Ca}$



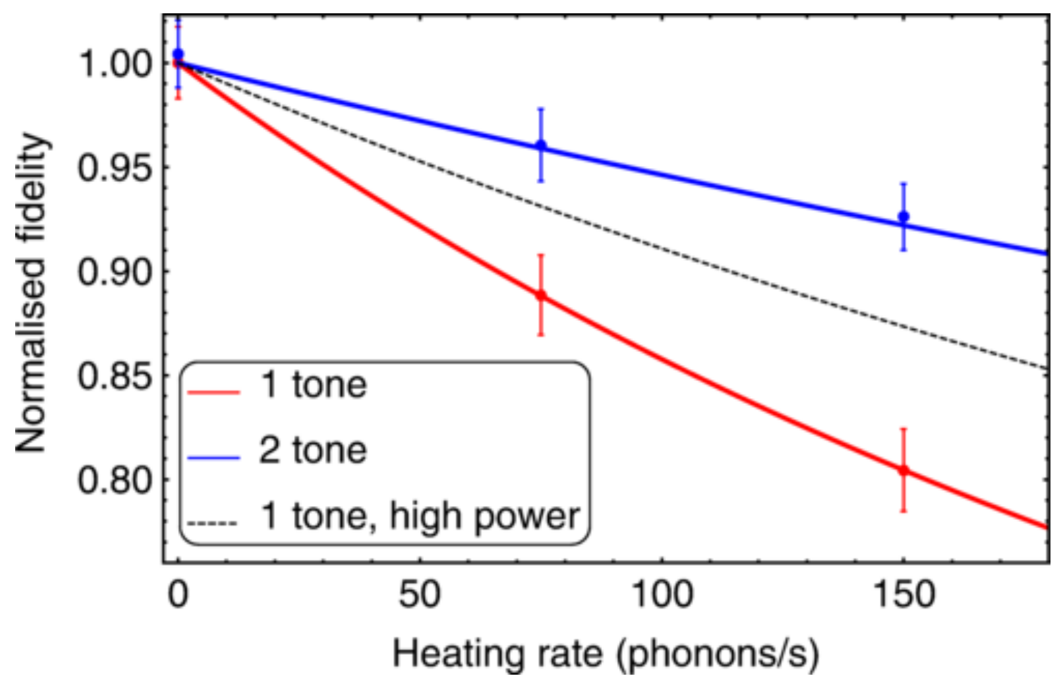
Photoionisation (PI) is a process that can be used to load an ion trap with ions from a neutral atoms source [2]. The process is composed of two transitions. First, the atom is excited on the $4s^2\ ^1\mathrm{S}_0 \leftrightarrow 4s4p\ ^1\mathrm{P}_1$ transition. Then, the electron is removed by exciting to the continuum with a 372nm laser. This method has many advantages with respect to the multi-photon ionisation process induced by a Nd:YAG laser used at present in our Penning trap experiment. More importantly this PI scheme is isotope selective, therefore allowing to directly create pure Coulomb crystals.

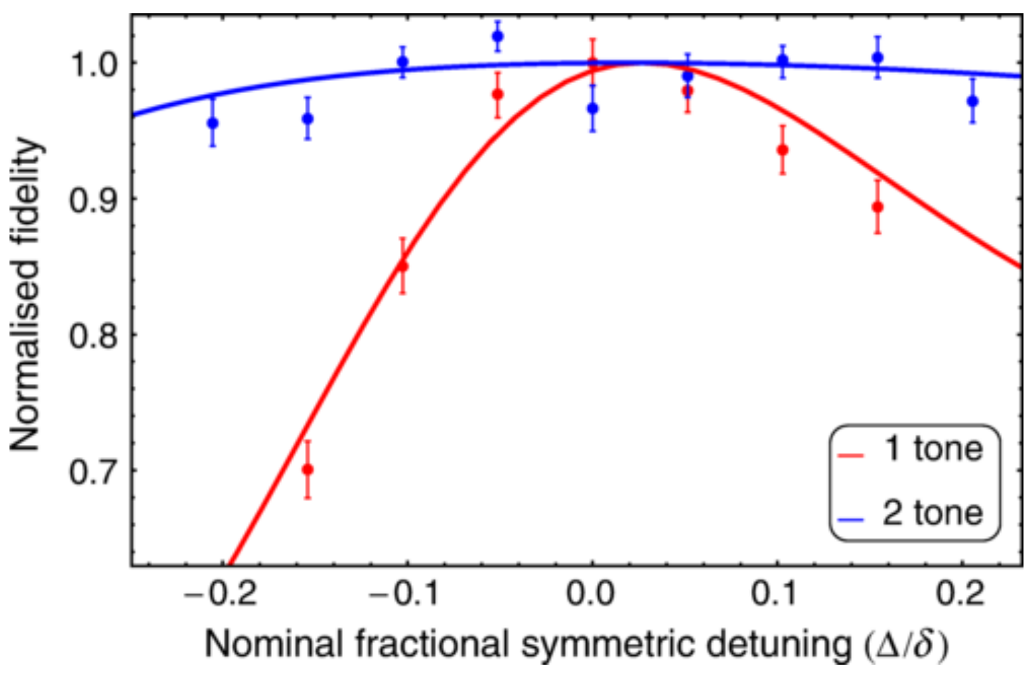


In the set up of the PI lasers, the 423nm wavelength was fine tuned via an external cavity diode laser with Littrow configuration. The requirement of high 372nm power required further beam shaping for optimal mode matching with the fibre.

OPTIMAL CONTROL

Optimal control of qubit gates encompasses experimental schemes that aim at increasing gate fidelity as well as making them more resilient to noise, by taking into account sources of experimental errors.





In ion traps, a common source of noise is motional decoherence and detuning from transitions. The above pictures show how implementing a multi-tone Mølmer-Sørensen scheme can help increase fidelity due to heating and symmetric detuning (study and pictures from [3]).

CONCLUSION

This work presented the current status on the realisation of a linear Paul trap. The photoionisation lasers were built and tested on the Penning trap, leading to pure Coulomb crystals. The imaging system was designed and tested on Zemax. The next steps will focus on the assembly of the imaging system and of the ovens in order to test PI in the linear Paul trap. Future work will aim at the sideband cooling of few ions (2-3) in order to implement optimal control techniques on two qubit gates.

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[2] N. Kjaergaard, L. Hornekaer, A. M. Thommesen, Z. Videsen, M. Drewsen, Isotope selective loading of an ion trap using resonance-enhanced two-photon ionization. Applied Physics B, vol. 71, no. 2, pp. 207–210, 2000.
[3] A. E. Webb, S. C. Webster, S. Collingbourne, D. Bretaud, A. M. Lawrence, S. Weidt, F. Mintert, and W. K. Hensinger, “Resilient entangling gates for trapped ions,” Physical Review Letters, vol. 121, no. 18, p. 180501, 2018