

# Towards a Scalable Logical Qubit: Yb and Ba Ion Toolkit

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Multi-species trapped ion quantum computing offers a promising solution to challenges around ground state cooling, optical crosstalk, and provides a natural separation between operations with contradictory requirements, particularly as the number of ions in a device is increased. We show work towards the implementation of a small logical qubit using Ytterbium (Yb) and Barium (Ba) ions in an X-junction chip trap. Our scheme uses Yb ions as data and ancilla qubits and Ba ions for cooling, with ions shuttled around between various locations on the X-junction chip as necessary for gate and measurement operations.

Preparation into the motional ground state of small ion chains can be achieved either through sideband resolved microwave pumping, or through Electromagnetic Induced Transparency (EIT) cooling applied to the Ba ions [1]. The Yb ions are sympathetically cooled by virtue of their shared motional modes, without impacting stored quantum states in the Yb ions. By encoding qubit states onto hyperfine levels of the ions ground state, we can employ microwave- and RF- driven single-qubit and multi-qubit Molmer-Sorensen (MS) quantum gates [2][3].

The application of a magnetic field gradient produces the spin motion coupling required by the MS gate, and results in separation of Zeeman levels for neighbouring ions. This frequency separation ensures low crosstalk between individually addressed single-qubit and two-qubit operations within the ion chain. Within this framework we present plans and initial progress toward the implementation of surface code fragments, compiling and optimising generic quantum circuits together with auxiliary operations for our specific scheme.

To trap Barium, we employ pulsed laser ablation (PLA) loading. A Q-switched Nd:YAG laser is being used to ablate the surface of a BaCl salt target, producing an atomized plume of neutral barium atoms, which is then ionized through resonance enhanced multi-photon ionisation (REMPI) for isotope selectivity. Additionally, we have a Ytterbium ablation target to compare the effectiveness of this method with the thermal ovens that are currently in use.

[1] Lechner, Regina, et al. 'Electromagnetically-Induced-Transparency Ground-State Cooling of Long Ion Strings'. *Physical Review A*, vol. 93, no. 5, May 2016, p. 053401. DOI.org (Crossref), <https://doi.org/10.1103/PhysRevA.93.053401>

[2] Weidt, S., et al. "Trapped-ion quantum logic with global radiation fields." *Physical Review Letters* 117.22 (2016): 220501. <https://doi.org/10.1103/PhysRevLett.117.220501>

[3] Negnevitsky, V., Marinelli, M., Mehta, K.K. et al. Repeated multi-qubit readout and feedback with a mixed-species trapped-ion register. *Nature* 563, 527–531 (2018). <https://doi.org/10.1038/s41586-018-0668-z>

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