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Sandia National Laboratories

Logical Cooling for Robust Analogue Quantum Simulation

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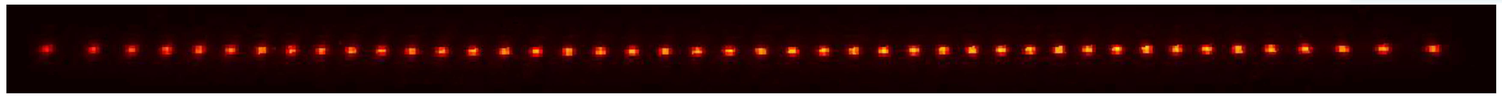
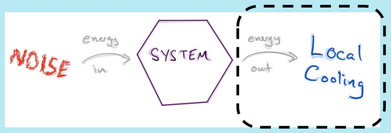


Analog Quantum Simulation Test Requires Upgrades to Existing Ion Trap Setup at Sandia

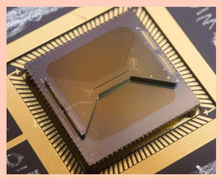
We might not be able to trust current quantum simulations!



Counteracts the effect of heating computational degrees of freedom, in a regime where standard-error correction and fault-tolerance cannot be applied (Partially Preserved Information)

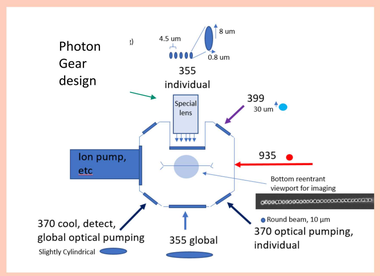
The Platform: $^{171}Yb^{+}$ Trapped Ions

Sandia HOA 2.0

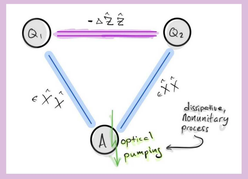


Surface trap
Position control
Optical access

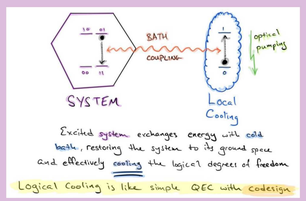
Layout: Top



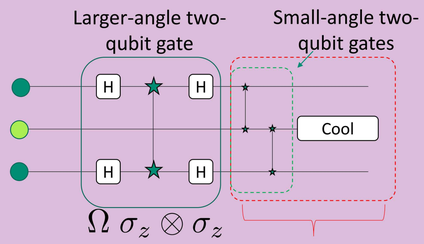
Simulator coupled to a cold bath instead of a hot one



Weakly pushes data qubits to $|00\rangle$ and $|11\rangle$



Pulse sequence for logical cooling:

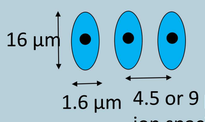


Implementation of Hamiltonian with ground states $|00\rangle$ and $|11\rangle$

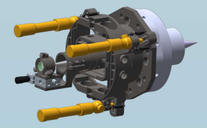
Logical cooling to pull energy out of system, thus keeping the system in $|00\rangle$ or $|11\rangle$

$$T_{\text{interaction}} \ll T_{\text{logical cooling}} \ll T_{\text{dissipation}}$$

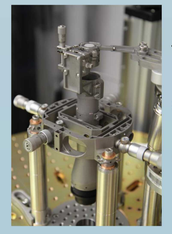
Individual Addressing Gate Beams: Reimaging 32 channel AOM



Tight tolerances require custom hardware for lens placement and alignment

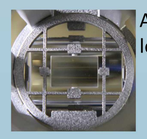


Lens mount to chamber for Custom Photon Gear Lens and reimaging optics



Tri-axis stage for active alignment of optical components

To avoid scatter off the trap edges, use cylindrical beams (tighter focus in horizontal direction)

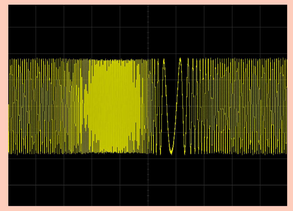


Actively aligned cylindrical lens in 3D printed metal

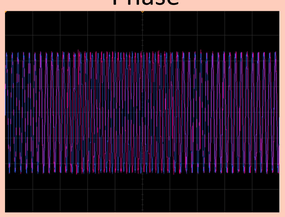
Extra Alignment Tools

Frequency, Phase, Amplitude control of dual toned DDS:
RF System on Chip (RFSoC)

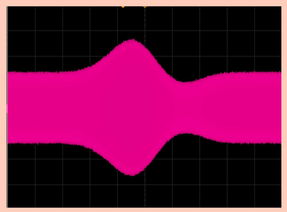
Frequency



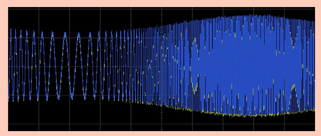
Phase



Amplitude

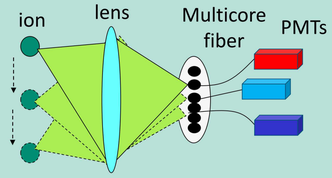


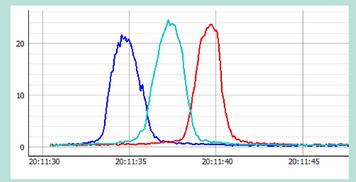
Phase Synchronous Modulation Across Channels



Distinguishable Detection: Separate detection zones for each ion

Example: Stepping a single ion through detection zones,
Crosstalk <3 % for neighboring cores (with minimal optimization)

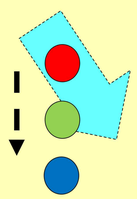


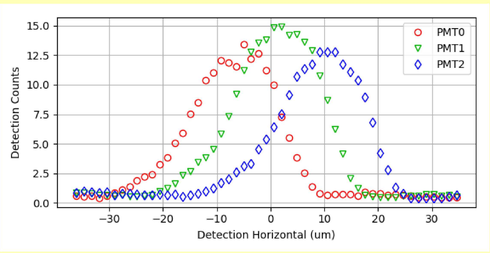


Time, as ion is uniformly stepped

Individual Optical Pumping:
Narrowly focused beam, with shuttling as needed

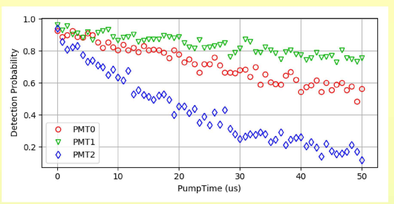
Moving detection light through three ions and looking at florescence of each ion

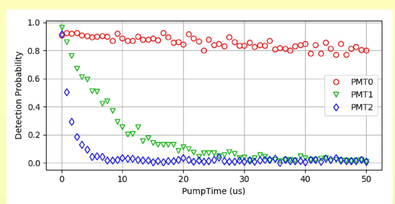


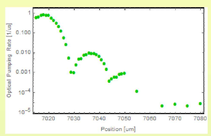


Ion spacing ~ 10 um,
beam waist ~7 um

Observing optical pumping efficiency on each of three ions for different optical pumping beam positions (ideally only one ion is optically pumped efficiently – not the case here)







Beam Profile is not gaussian

Mitigation:
1) Shuttle ancilla ion for optical pumping step
2) Tighter focus by sending beam through imaging optics

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