

Reaching extremely high vacuum and recent progress towards developing a trapped-ion quantum simulator with mid-circuit measurements

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Trapped-ion systems are one of the leading platforms for quantum information processing (QIP) and have been shown to be well suited for exploring novel many-body physics, including measurement-driven quantum phase transitions. Realizing these experiments requires ‘mid-circuit’ measurement and resets (MCMR) of a subsystem, as well as the ability to obtain large datasets to build up statistics. These requirements translate to seemingly contradictory hardware design goals - to maximize optical access for MCMR or minimize the vacuum pressure to prevent background collisions that lead to frequent ion loss. While cryogenic chambers are used to reach extreme high vacuum (XHV, $< 10^{-12}$ mbar), these systems impose constraints on optical access, placing limits on high numerical aperture (NA) addressing and detection.

Here we present the development of a room-temperature trapped-ion quantum simulator engineered to enable MCMR through high NA detection and addressing of individual qubits, while operating approaching the XHV regime. Using molecular-flow simulations, we optimize the chamber geometry, conductance pathways, and pumping configuration to maximize the effective pumping speed at the ion location. From measured ion-background gas collision rates, we estimate a local pressure of 3.3×10^{-12} mbar, in agreement with ion-gauge measurements, resulting in a collisional lifetime of 1.9 hrs/ion. These capabilities open exciting opportunities to observe new classes of quantum states resulting from the competition of partial measurement and coherent evolution.

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