**Temporal multiplexing for improved ion-photon interface**

Trapped single ions are amongst the most advanced platforms for distributed quantum information processing (DQIP) with photonic interconnects. One of the main requirements for the practical realization of DQIP is to establish a high-rate and high-fidelity remote entanglement. Towards reaching this goal, recent experimental demonstrations have shown significant progress by creating lab-scale quantum networks of the trapped-ion quantum processors in a free-space photon generation/coupling configuration. Furthermore, near-optimal photon extraction efficiencies have been accomplished, along with quantum frequency conversion to the telecom band, through ion-cavity interfaces. However, in heralded quantum entanglement schemes reaching high entanglement rates at distances longer than a few kilometers is intrinsically limited by the communication latency resulting from the photon round-trip travel time across the channel. To address this problem, we implement a temporally multiplexed single-photon source through the coherent transport of a chain of nine calcium ions over 74um within a 94us, synchronized with single ion excitation. This method utilizes a theoretically optimal ion-chain transport function, derived via inverse engineering. We confirm the non-classical nature of these multiplexed, on-demand photons through Hanbury-Brown-Twiss experiments, yielding a g2 value of 0.0595. Together with our supplementary measurements, this result indicates a negligible crosstalk between the multiplexed modes. Our proof-of-principal demonstrations mark a step towards enhancing the remote entanglement rates for large-scale quantum networks with trapped ions.