Measurement-device-independent verification of a quantum memory

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Abstract

Verification of quantum memories is indispensable in large scale application scenarios of quantum information. In previous quantum memory experiments, process tomography is the most frequently used verification scheme. But this scheme is vulnerable under attacks in every aspect. Here, by following the proposal of [PhysRevX.8.021033], we did:

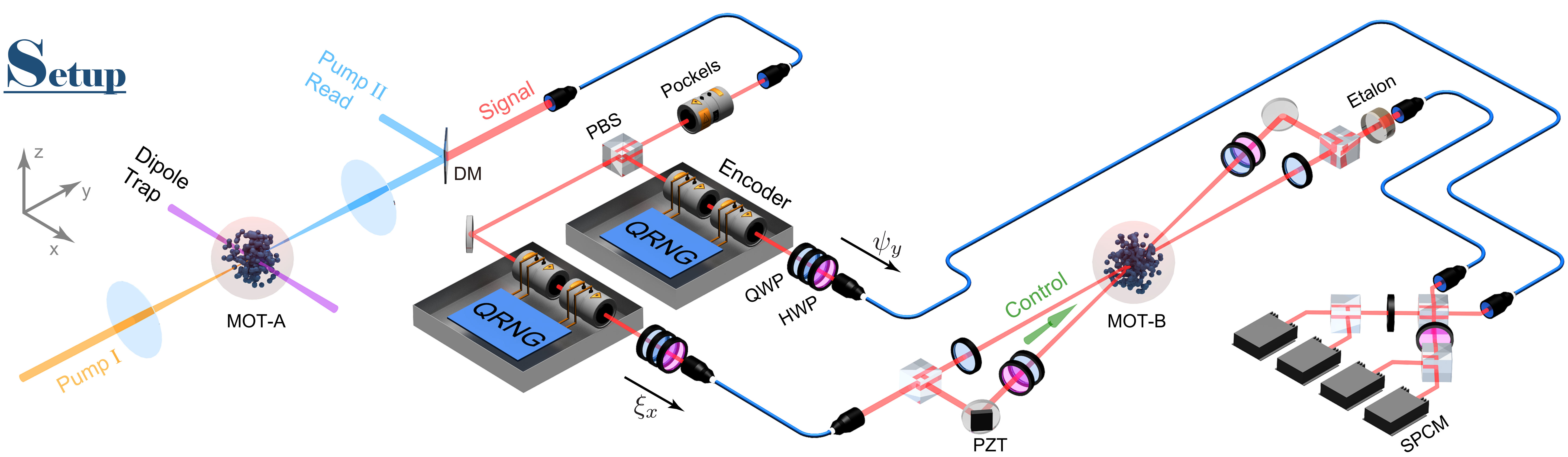
1. verify a quantum memory in the measurement-device-independent fashion for the first time.
2. ensure a trusted state preparation process by using a Rydberg single-photon source and a random state preparation.

Schematic

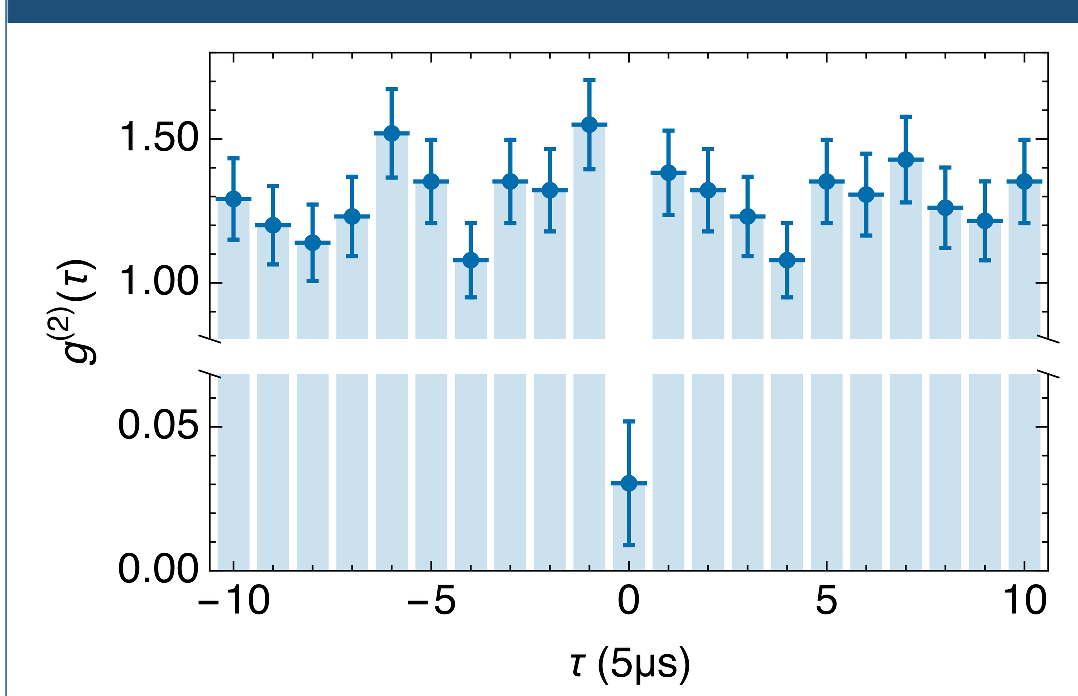
Supposing the operation of a quantum memory is $\mathcal{N}$, then its Choi state is $\mathbb{J}_{\mathcal{N}} = (\mathcal{N}\otimes\mathbb{I})|\Phi^+\rangle\langle\Phi^+|$. We can verify it is not an entanglement-breaking if the witness $\langle W\rangle > 0$ is fulfilled. This verification process could be achieved through playing a semi-quantum game. The process of this game is very similar with a MDI-QKD experiment, with one of signal photon be stored in the quantum memory.

In our experiment, the quantum memory to be tested is based on electromagnetically induced transparency(EIT). Signal photons are generated through a Rydberg atomic ensemble. The encoding process is achieve by quantum random number gerators(QRNG).

Setup



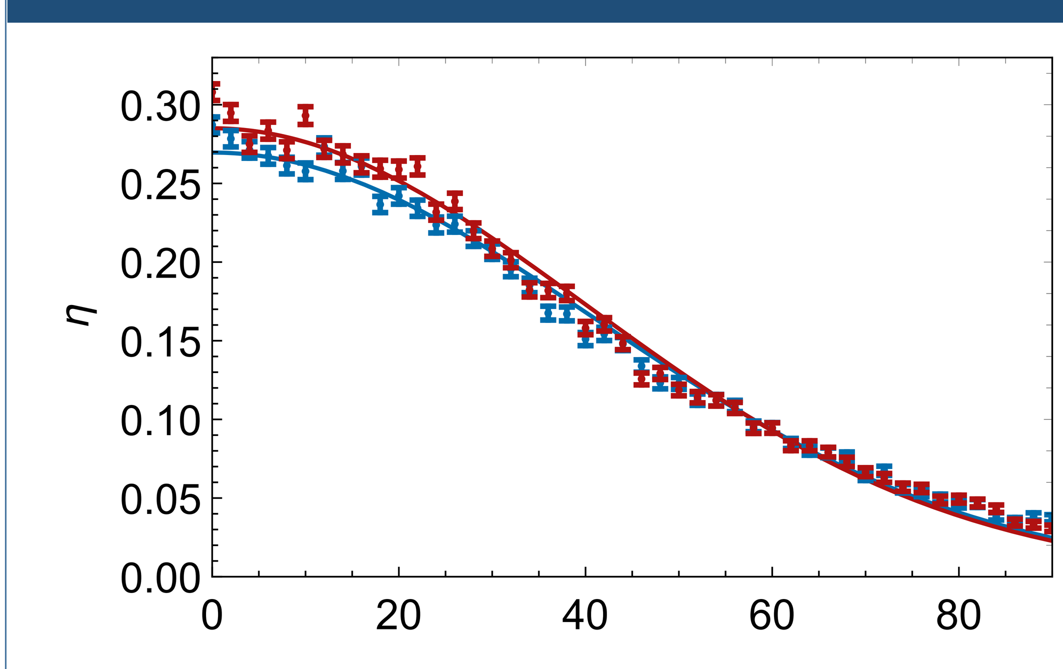
Rydberg single-photon source



Photon efficiency: $p = 0.06$

Hanbury-Brown-Twiss experiment: $g^{(2)}(0) = 0.03(2)$

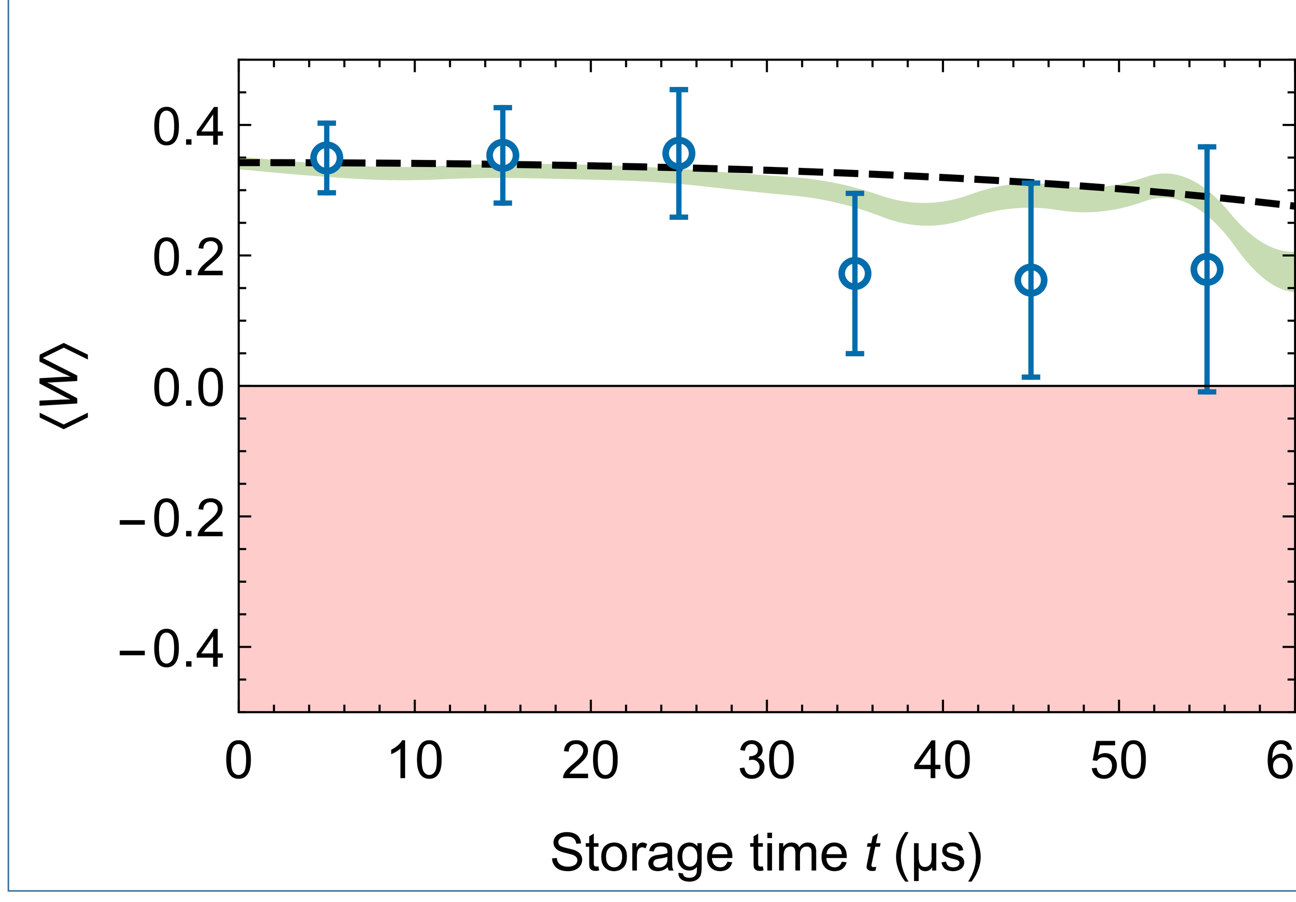
EIT quantum memory



Storage efficiency: $\eta(0) \approx 26\%$

Storage lifetime: $\tau_{life} \approx 57\mu s$

Results



Blue: experiment

Green: simulation

Black: theory

Conclusion

We verify a EIT quantum memory via MDI scheme for the first time. Meanwhile we ensure a secure state preparation via Rydberg single-photon source and QRNG-based encoding.

Our method can be straightforwardly applied to other kinds of quantum memories and quantum processors, such as quantum frequency converters, quantum nondemolition measurement devices, etc.

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