Quantum learning advantage on a scalable photonic platform

Zheng-Hao Liu¶,[1,*] Romain Brunel,[1,*] Emil E. B. Østergaard,[1] Oscar Cordero,[1] Senrui Chen,[2] Yat Wong,[2] Jens A. H. Nielsen,[1] Axel B. Bregnsbo,[1] Sisi Zhou,[3,4] Hsin-Yuan Huang,[5,6,7] Changhun Oh,[8] Liang Jiang,[2] John Preskill,[6] Jonas S. Neergaard-Nielsen,[1] and Ulrik L. Andersen[1,†]

[1] *Center for Macroscopic Quantum States (bigQ), Department of Physics, Technical University of Denmark, Fysikvej, 2800 Kongens Lyngby, Denmark*
[2] *Pritzker School of Molecular Engineering, The University of Chicago, Chicago, Illinois 60637, USA*
[3] *Perimeter Institute for Theoretical Physics, Waterloo, Ontario N2L 2Y5, Canada*
[4] *Department of Physics and Astronomy and Institute for Quantum Computing, University of Waterloo, Ontario N2L 2Y5, Canada*
[5] *Google Quantum AI, Venice, CA, USA*
[6] *Institute for Quantum Information and Matter, California Institute of Technology, Pasadena, CA 91125, USA*
[7] *Center for Theoretical Physics, Massachusetts Institute of Technology, Cambridge, MA 02139, USA*
[8] *Department of Physics, Korea Advanced Institute of Science and Technology, Daejeon 34141, Korea*

(Dated: February 18, 2025)

Experimental demonstration of quantum advantage in learning a **multi-mode bosonic displacement channel.**

Up to 10^{11} **fewer samples** than any classical strategy.

https://arxiv.org/pdf/2502.07770

Applications of learning the properties of this process

- Gravitational wave detection
- Dark matter searches
- Microscopic force sensing

Any CV noise channel can be tailored into a random displacement channel by twirling

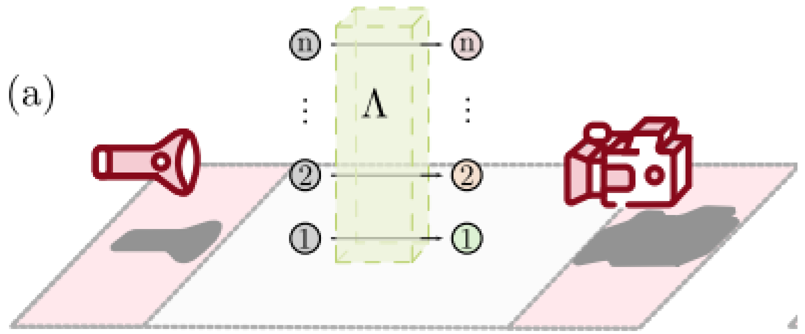
Task

Learn the properties of an unknow n-mode displacement process

Model the random amplitude and phase noise in bosonic channels

Classical approach

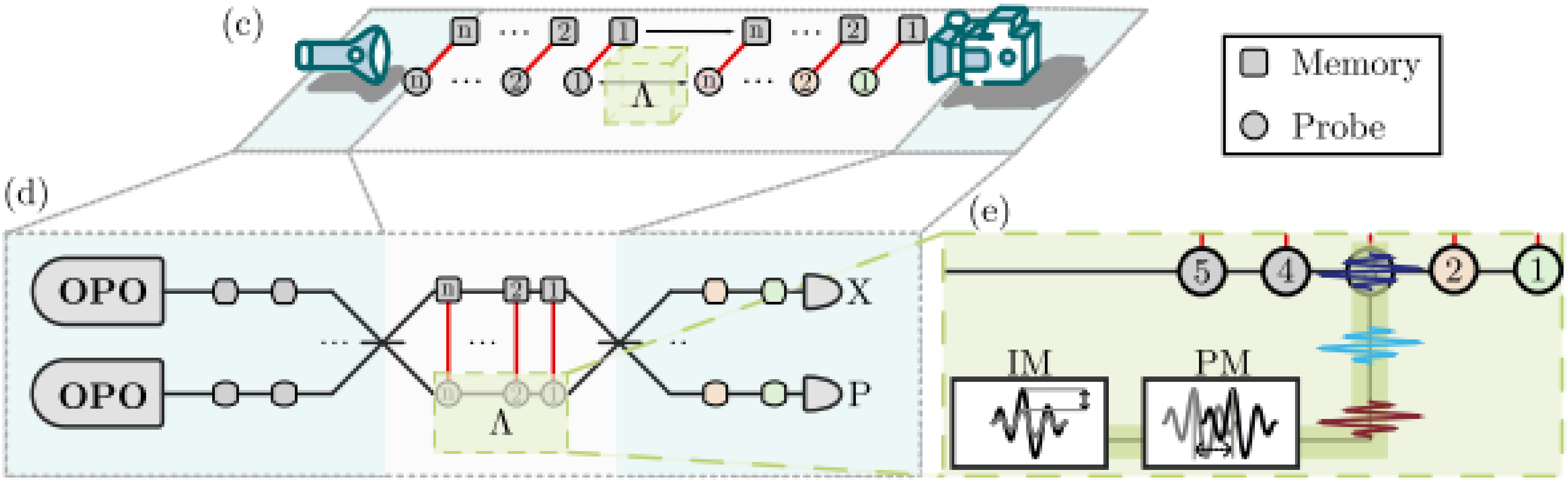
1. Send probe state
2. Measure
3. Repeat



Sample complexity: exponential in n (system size)

Quantum-enhanced protocol

- Entangle probe and memory states
- Apply channel to probe
- Perform Bell measurement



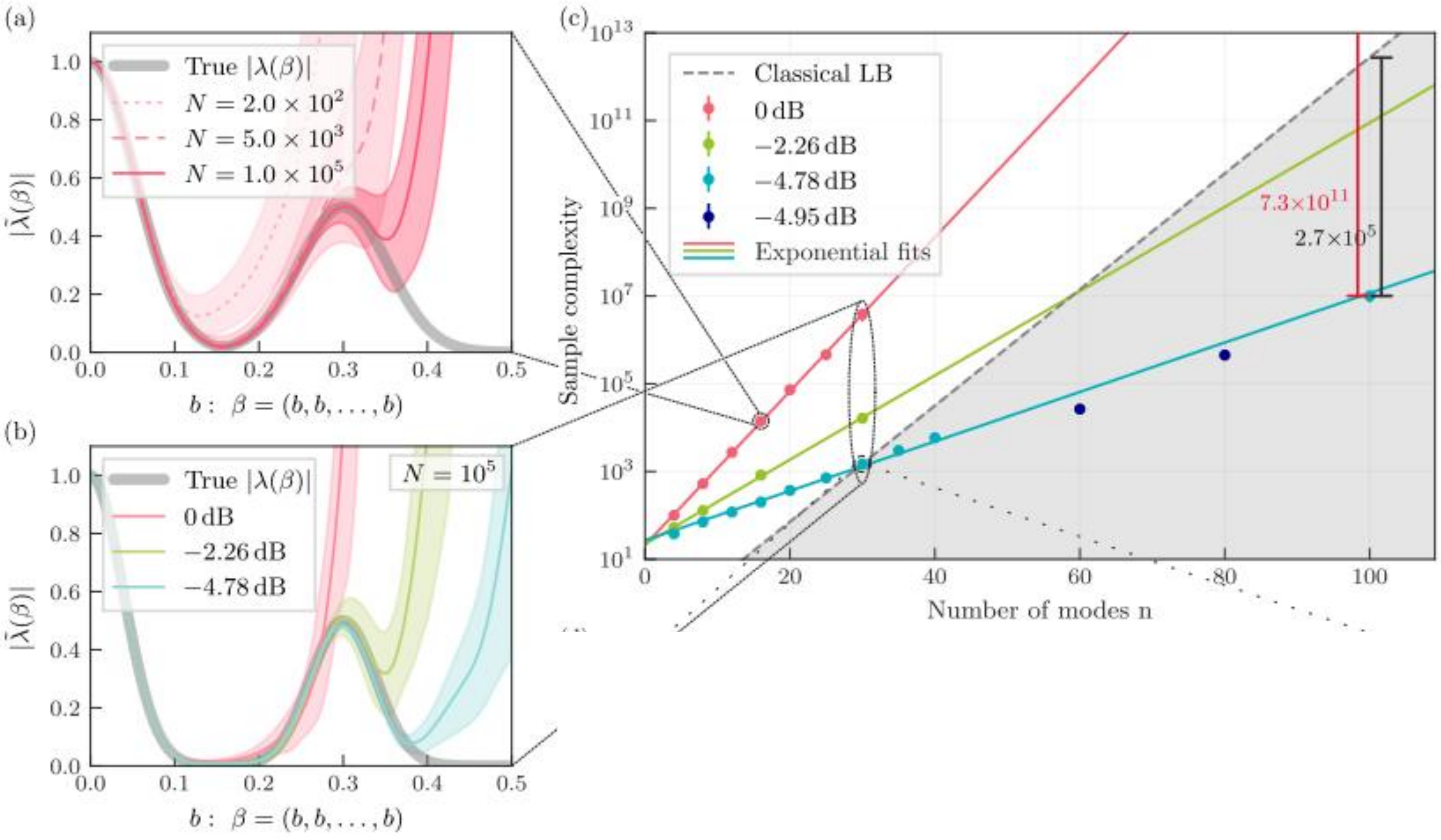
Two-mode squeezing (entanglement): reduces the sample complexity.

Results

Reconstruction of the characteristic function

For different numbers of samples

For different levels of squeezing



➡ Scaling of sample complexity improves with two-mode squeezing