

Learning and computation in quantum systems

Premio Federico Tonielli 2026

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My research path



Quantum information and computing

Quantum learning, quantum algorithms and noise, mathematical tools

Research map

Quantum learning

Qubits

[1] Optimal learning of quantum channels in diamond distance
Antonio Anna Mele, Lennart Bittel.
Nature Physics, accepted (2026)

[2] Quantum memory advantage for quantum process tomography
Carlos Bravo-Prieto, Weiyuan Gong, Antonio Anna Mele.
2026

[3][†] Adaptivity is all you need: Optimal stabilizer learning using just single-copy measurements
Lennart Bittel, Jens Eisert, Weiyuan Gong, Antonio Anna Mele, Louis Schatzki.
2026

Fermions

[6] Efficient learning of quantum states prepared with few fermionic non-Gaussian gates
Antonio Anna Mele, Yaroslav Herasymenko.
PRX Quantum (2025)

[7] Optimal trace-distance bounds for free-fermionic states: Testing and improved tomography
Lennart Bittel, Antonio Anna Mele, Jens Eisert, Lorenzo Leone.
PRX Quantum (2025)

[8] Learning fermionic correlations by evolving with random translationally invariant Hamiltonians
Janek Denzler, Antonio Anna Mele, Ellen Derbyshire, Tommaso Guaita, Jens Eisert.
Physical Review Letters (2024)

[9] PAC-learning of free-fermionic states is NP-hard
Lennart Bittel, Antonio Anna Mele, Jens Eisert, Lorenzo Leone.
Quantum (2025)

[10] Testing quantum Gaussianity with constant sample complexity
Mahtab Yaghubi Rad, Ricard Puig, Saksham Hassanandani, Luke Coffman, Jens Eisert, Carlos Bravo-Prieto, Antonio Anna Mele.
2026

[4] Real classical shadows
Maxwell West, Antonio Anna Mele, Martin Larocca, Marco Cerezo.
Journal of Physics A (2025)

[5] Experimental measurement and a physical interpretation of quantum shadow enumerators
Daniel Miller, Kyano Levi, Lukas Postler, Alex Steiner, Lennart Bittel, Gregory A. L. White, Yifan Tang, Eric J. Kuehnke, Antonio Anna Mele, Sumeet Khatri, Lorenzo Leone, Jose Carrasco, Christian D. Marciniak, Ivan Pogorelov, Milena Guevara-Bertsch, Robert Freund, Rainer Blatt, Philipp Schindler, Thomas Monz, Martin Ringbauer, Jens Eisert.
Physical Review Research (2026)

Bosons

[11] Learning quantum states of continuous-variable systems
Francesco Anna Mele, Antonio Anna Mele, Lennart Bittel, Jens Eisert, Vittorio Giovannetti, Ludovico Lami, Lorenzo Leone, Salvatore F. E. Oliviero.
Nature Physics (2025)

[12] Optimal estimates of trace distance between bosonic Gaussian states and applications to learning
Lennart Bittel, Francesco Anna Mele, Antonio Anna Mele, Salvatore Tirone, Ludovico Lami.
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[13] Energy-independent tomography of Gaussian states
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[14][†] When are bosonic Gaussian states classical to learn?
Senrui Chen, Antonio Anna Mele, Francesco Anna Mele, John Preskill.
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[15][†] Efficient learning of bosonic Gaussian unitaries
Marco Fanizza, Vishnu Iyer, Junseo Lee, Antonio Anna Mele, Francesco Anna Mele.
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Quantum algorithms and noise

Noisy circuits

[16] Noise-induced shallow circuits and the absence of barren plateaus
Antonio Anna Mele, Armando Angrisani, Soumik Ghosh, Sumeet Khatri, Jens Eisert, Daniel Stilck França, Yihui Quek.
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[17] Simulating quantum circuits with arbitrary local noise using Pauli propagation
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PRX Quantum (2026)

Variational algorithms

[18] Avoiding barren plateaus via transferability of smooth solutions in Hamiltonian variational ansatz
Antonio Anna Mele, Glen Bigan Mbeng, Giuseppe Ernesto Santoro, Mario Collura, Pietro Torta.
Physical Review A (2022)

[19] Stochastic noise can be helpful for variational quantum algorithms
Junyu Liu, Frederik Wilde, Antonio Anna Mele, Xin Jin, Liang Jiang, Jens Eisert.
Physical Review A (2025)

[20] Exploiting symmetry in variational quantum machine learning
Johannes Jakob Meyer, Marian Mularski, Elies Gil-Fuster, Antonio Anna Mele, Francesco Arzani, Alissa Wilms, Jens Eisert.
PRX Quantum (2023)

Verifiable quantum advantage

[21] Towards verifiable quantum advantage with random circuits: Observables that survive concentration
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2026

Mathematical tools and structure

Haar, Clifford and representation theory

[22] Introduction to Haar measure tools in quantum information: A beginner’s tutorial
Antonio Anna Mele.
Quantum (2024)

[23][†] A complete theory of the Clifford commutant
Lennart Bittel, Jens Eisert, Lorenzo Leone, Antonio Anna Mele, Salvatore F. E. Oliviero.
Quantum (2026)

[24] Lecture Notes on Representation Theory for Quantum Information (QMATH Masterclass 2025, Copenhagen)
Antonio Anna Mele.
Lecture notes (2026)

Randomness

[25] Strong unitary designs in optimal depth and space
Teodor Parella-Dilmé, Júlia Barberà-Rodríguez, Salvatore F. E. Oliviero, Antonio Anna Mele.
2026

[26] Random ensembles of symplectic and unitary states are indistinguishable
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Quantum resource theories

[27] A unified approach to quantum resource theories and a new class of free operations
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[28] Characterizing quantum resourcefulness via group-Fourier decompositions
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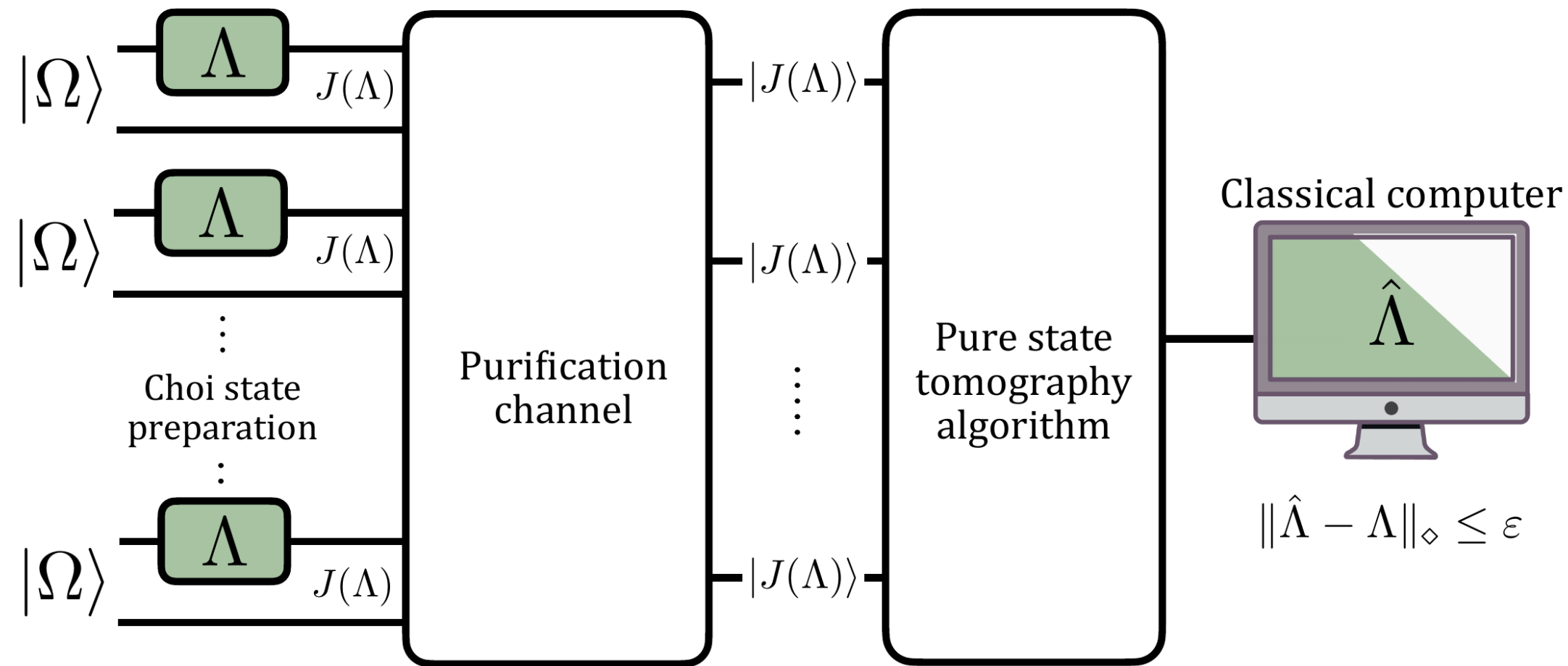
[29] Analyzing the free states of one quantum resource theory as resource states of another
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Advanced Quantum Technologies (2026)

* Equal contribution † Alphabetical author order

Optimal quantum process tomography

How many channel uses are needed to characterize a channel?

Choi state



Query complexity [1]

$$N = O\left(\frac{d_{\text{in}} d_{\text{out}} k}{\varepsilon^2}\right)$$

Kraus rank k

Diamond-distance guarantee

$$\|\hat{\Lambda} - \Lambda\|_{\diamond} \leq \varepsilon$$

Worst-case guarantee,
including entangled inputs

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Learning fermionic states beyond Gaussianity

Gaussian states [7]

Correlation matrices give a stable description of the state

$$\Gamma_{jk} = -\frac{i}{2} \text{Tr}(\rho[c_j, c_k])$$

$$\|\rho - \sigma\|_1 \leq \frac{1}{2} \|\Gamma(\rho) - \Gamma(\sigma)\|_1$$

Optimal trace-distance bounds for robust tomography

[7] Optimal trace-distance bounds for free-fermionic states: Testing and improved tomography

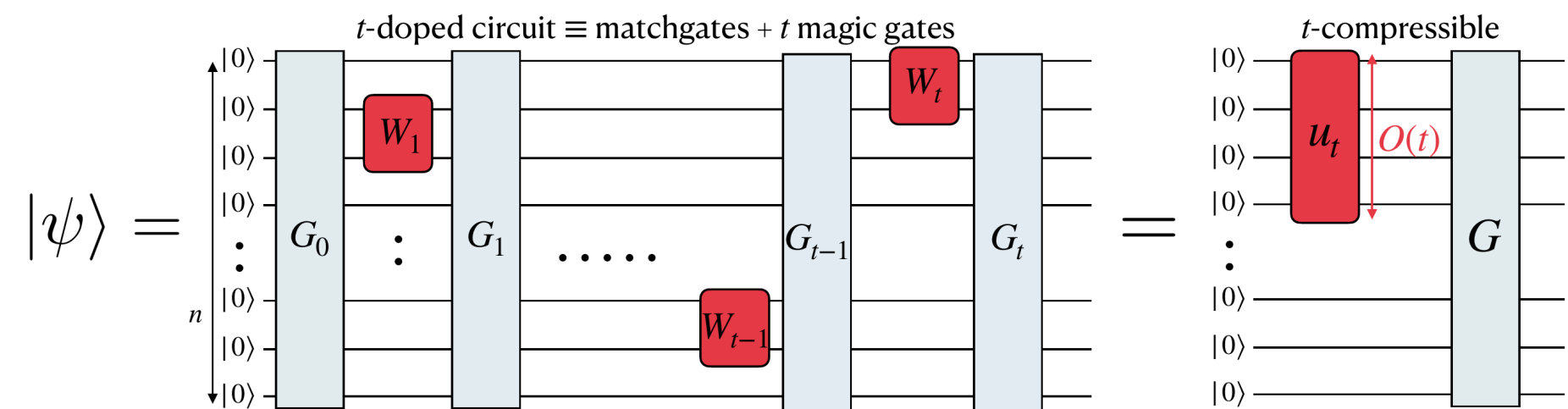
Lennart Bittel, Antonio Anna Mele, Jens Eisert, Lorenzo Leone.

PRX Quantum 6, 030341 (2025).

Few non-Gaussian gates [6]

Compress non-Gaussianity into a small subsystem

a) Non-Gaussianity compression



$$N, T_{\text{cl}} = \text{poly}(n, 2^t)$$

Single-copy measurements, fixed Majorana locality

Efficient when $t = O(\log n)$

[6] Efficient learning of quantum states prepared with few fermionic non-Gaussian gates

Antonio Anna Mele, Yaroslav Herasymenko.

PRX Quantum 6, 010319 (2025).

Learning bosonic states beyond Gaussianity

Gaussian structure enables efficient continuous-variable tomography [11]

Energy bounds alone do not ensure efficiency

$$N = \Omega(\varepsilon^{-2n})$$

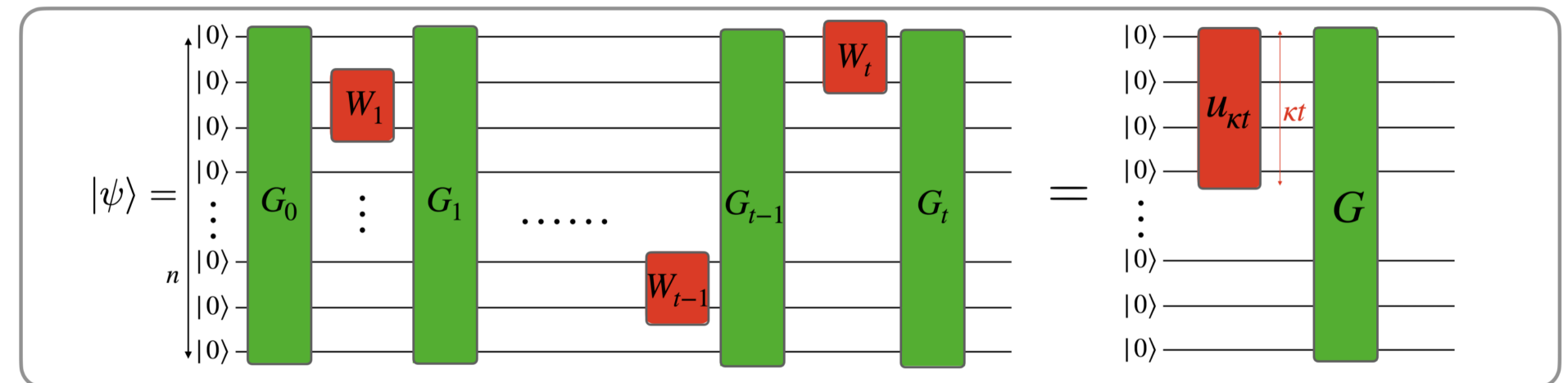
n modes with bounded mean energy per mode

Gaussian structure

First and second moments enable efficient trace-distance tomography

Beyond Gaussian states

Few local non-Gaussian gates confine non-Gaussianity to a small subsystem



Efficient learning when $\kappa t = O(1)$

[11] Learning quantum states of continuous-variable systems

Francesco Anna Mele, **Antonio Anna Mele**, Lennart Bittel, Jens Eisert, Vittorio Giovannetti, Ludovico Lami, Lorenzo Leone, Salvatore F. E. Oliviero.

Nature Physics 21, 2002–2008 (2025).

Other works in learning bosonic systems

Trace-distance bounds [12]

Optimal trace-distance estimates
from errors in first and second moments

Gaussian unitaries [15][†]

Learning transformations with an
energy-constrained diamond guarantee

Energy-independent tomography [13]

Adaptive unsqueezing gives a double-exponential
improvement in energy dependence over previous
protocols.

Gaussianity testing [10]

(Distinguishing Gaussian from non-Gaussian)

For pure inputs: a number of copies
independent of system size

[12] Optimal estimates of trace distance between bosonic
Gaussian states and applications to learning

Lennart Bittel, Francesco Anna Mele, **Antonio Anna Mele**,
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Quantum 9, 1769 (2025).

[13] Energy-independent tomography of Gaussian states

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Luke Coffman, Jens Eisert, Carlos Bravo-Prieto,
Antonio Anna Mele. 2026.

Separations in learning

Quantum channels [2]

Measure after every query, or retain quantum memory

$$N_{\text{classical memory}} = \Theta(D^3/\varepsilon^2)$$

$$N_{\text{quantum memory}} = \Theta(D^2/\varepsilon^2)$$

$$D = d_{\text{in}} d_{\text{out}}$$

Stabilizer states [3][†]

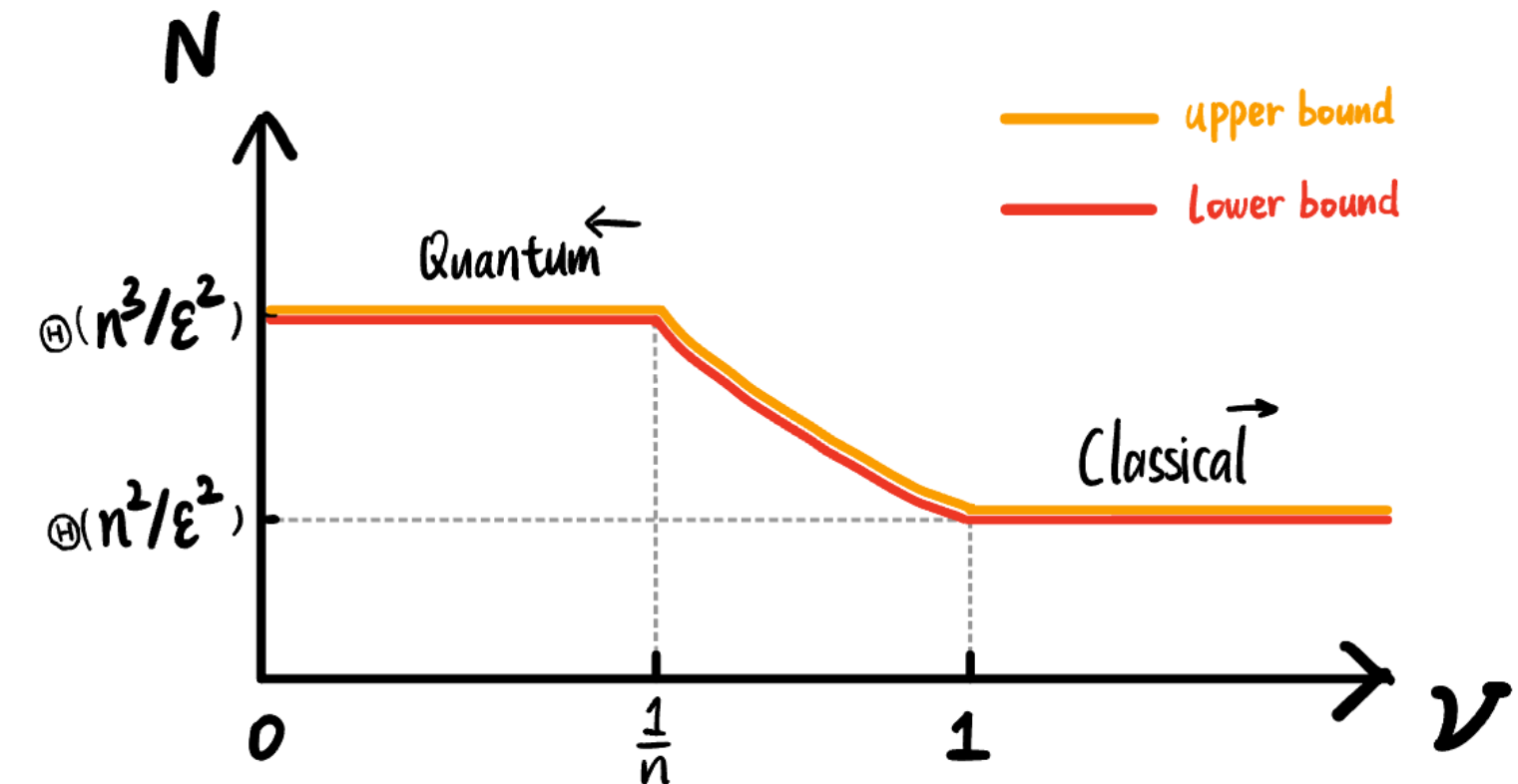
$$N_{\text{nonadaptive, single-copy}} = \Omega(n^2)$$

$$N_{\text{adaptive, single-copy}} = \Theta(n)$$

Bosonic Gaussian states [14][†]

$$N_{\text{single-copy}}^{\text{cold}} = \Omega(n^3), \quad N_{\text{collective}}^{\text{cold}} = \Theta(n^2)$$

$$N_{\text{heterodyne}}^{\text{warm}} = N_{\text{collective}}^{\text{warm}} = \Theta(n^2)$$



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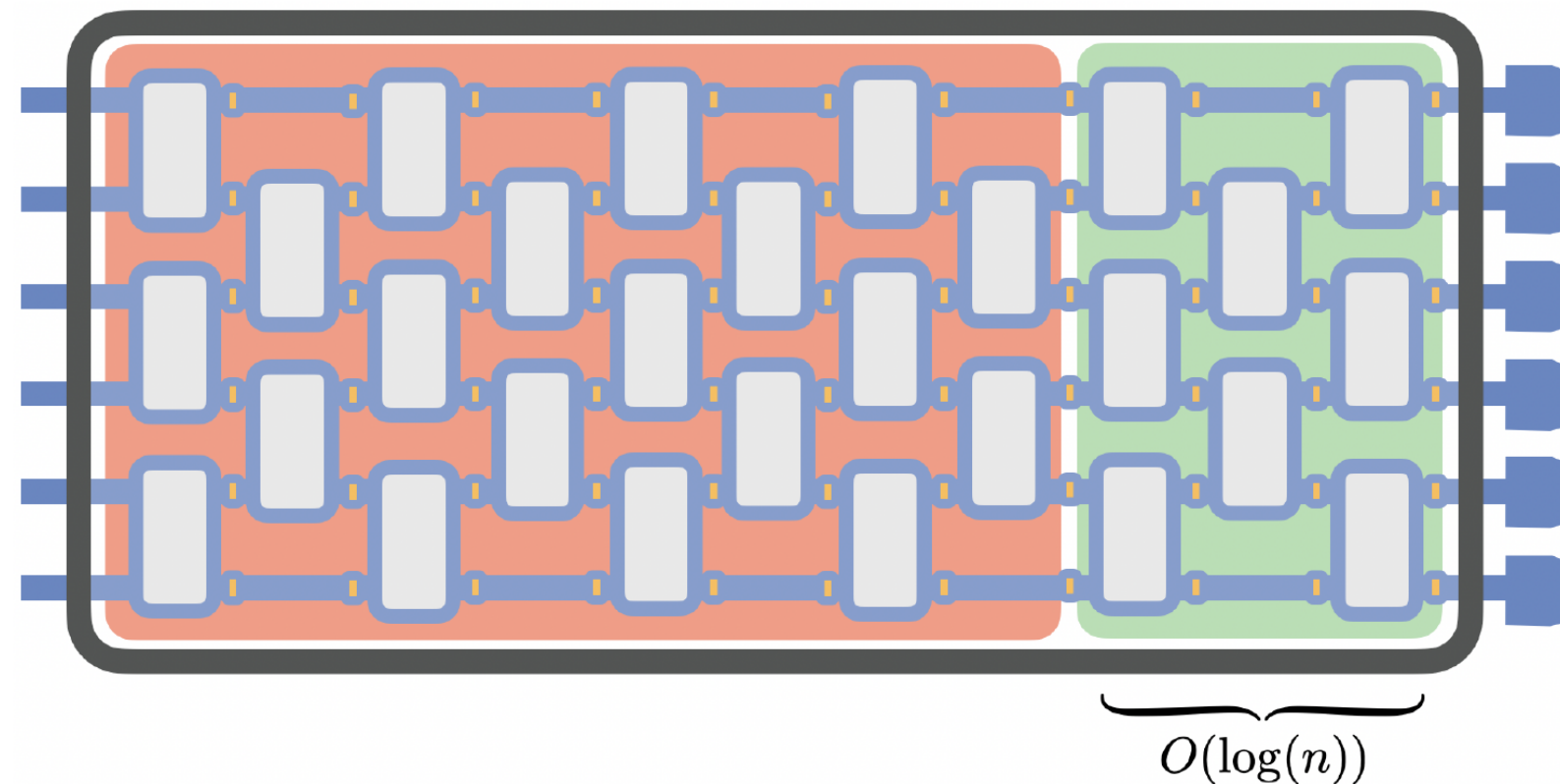
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Local noise induces an effective shallow circuit

For typical random circuits, local noise limits the relevant depth



Exponential forgetting [16]

$$\mathbb{E}_C |\langle O \rangle_{\text{full}} - \langle O \rangle_{\text{last } m}| \leq \|O\|_{\infty} e^{-\alpha m}$$

$$L_{\text{eff}} = O(\log n)$$

Fixed local noise,
inverse-polynomial accuracy

Classical simulation [17]

Pauli propagation with controlled truncation

$$T = \text{poly}(n, \varepsilon^{-1}, \delta^{-1})$$

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Nature Physics 22, 751–756 (2026).

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PRX Quantum 7, 020313 (2026).

Out-of-time-order correlators (OTOCs)

An OTOC quantifies how a local perturbation B affects a distant operator M .

Task: estimate the OTOC

Random circuit U , prepared state ρ ,
distant local Pauli operators B and M

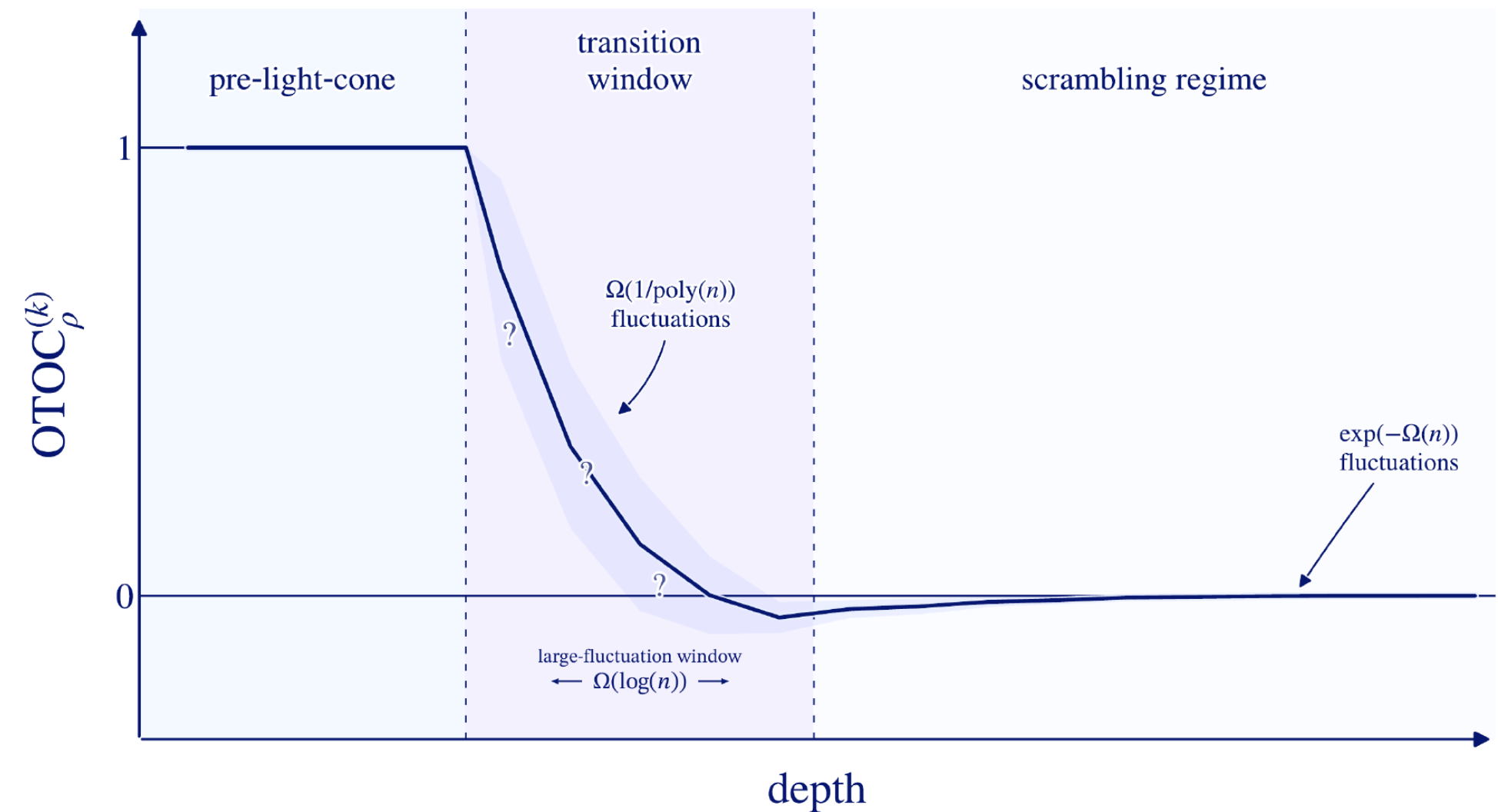
$$B_U = U^\dagger B U$$

$$\text{OTOC}_\rho^{(k)}(U) = \text{Tr}[\rho(B_U M)^{2k}]$$

$$\left| \hat{z} - \text{OTOC}_\rho^{(k)}(U) \right| \leq \varepsilon, \quad \varepsilon = \frac{1}{\text{poly}(n)}$$

Fluctuations survive at intermediate depth

$$\text{Var}_U \left[\text{OTOC}_\rho^{(k)}(U) \right] \geq \frac{1}{\text{poly}(n)}$$



Collaboration with Google Quantum AI

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* Equal contribution

Mathematical tools and structure

Clifford commutant [23][†]

Higher-order symmetries of the qubit Clifford group

$$[O, C^{\otimes k}] = 0 \quad \forall C \in C_n$$

QEC and magic-state resource theory

$$\text{Diagram} \stackrel{(i)}{=} \text{Diagram} = \Omega_6 T_{(12)} T_{(34)} T_{(56)},$$

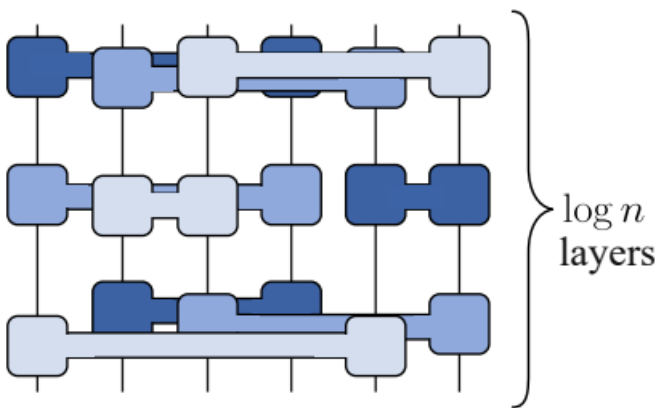
Haar and representation theory

Haar integration, moment operators and representation theory lecture notes [22, 24]

Strong unitary designs [25]

$$d = \Theta(\log n) \quad (n \text{ qubits})$$

All-to-all connectivity



[22] Introduction to Haar measure tools in quantum information: A beginner's tutorial

Antonio Anna Mele. *Quantum* 8, 1340 (2024).

[23][†] A complete theory of the Clifford commutant

Lennart Bittel, Jens Eisert, Lorenzo Leone, Antonio Anna Mele, Salvatore F. E. Oliviero. *Quantum* 10, 2171 (2026).

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Teaching and mentoring

QMATH, Copenhagen · August 2025

Representation theory crash course

AIMS, Cape Town · October 2025

Haar integration tools

Freie Universität Berlin · 2022–23

Quantum information theory

Teaching assistant

QISCA Winter School · January 2026

Learning t -doped Gaussian states

EPFL Bernoulli Center · May 2026

Bosonic and fermionic quantum learning

MSc mentoring · Diego Polimeni · 2025

Fault-tolerant quantum computation

Future directions

Quantum algorithms

Fault-tolerant quantum computing

AI-powered research

Thank you so much for your attention

Antonio Anna Mele

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Learning fermionic correlations by evolving with random translationally invariant Hamiltonians
Physical Review Letters 133, 240604 (2024)
- [9]** Lennart Bittel, **Antonio Anna Mele**, Jens Eisert, Lorenzo Leone.
PAC-learning of free-fermionic states is NP-hard
Quantum 9, 1665 (2025)
- [10]** Mahtab Yaghubi Rad, Ricard Puig, Saksham Hassanandani, Luke Coffman, Jens Eisert, Carlos Bravo-Prieto, **Antonio Anna Mele**.
Testing quantum Gaussianity with constant sample complexity
2026

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Qubits and quantum channels

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Journal of Physics A: Mathematical and Theoretical 58, 245304 (2025)
- [5]** Daniel Miller, Kyano Levi, Lukas Postler, Alex Steiner, Lennart Bittel, Gregory A. L. White, Yifan Tang, Eric J. Kuehnke, **Antonio Anna Mele**, Sumeet Khatri, Lorenzo Leone, Jose Carrasco, Christian D. Marciniak, Ivan Pogorelov, Milena Guevara-Bertsch, Robert Freund, Rainer Blatt, Philipp Schindler, Thomas Monz, Martin Ringbauer, Jens Eisert.
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Physical Review Research 8, 023318 (2026)

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- [21]** **Antonio Anna Mele**^{*}, Francesco Anna Mele^{*}, Jarrod R. McClean, Thomas E. O’Brien.
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