Implementing POVMs

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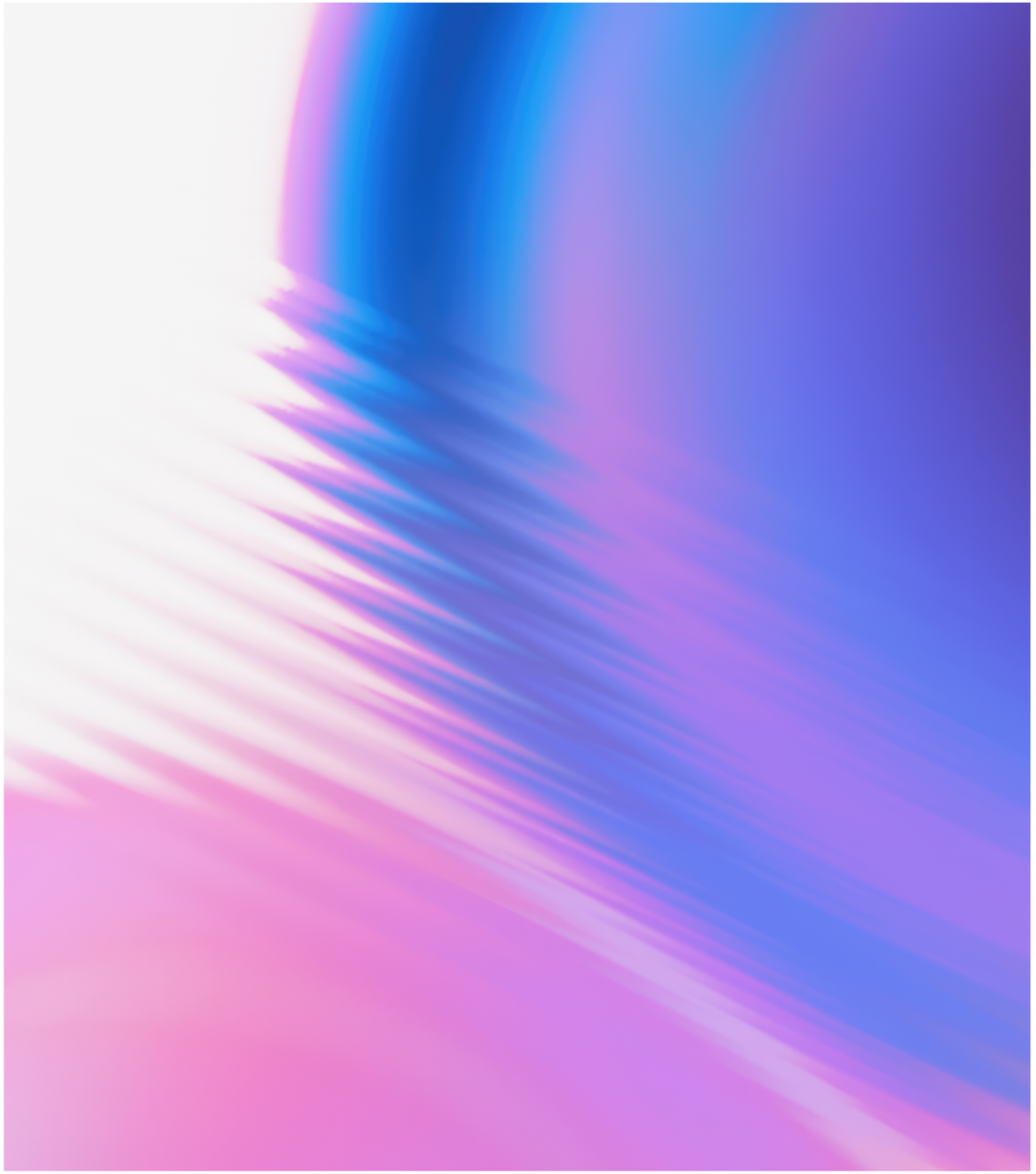

Mixed projective measurements

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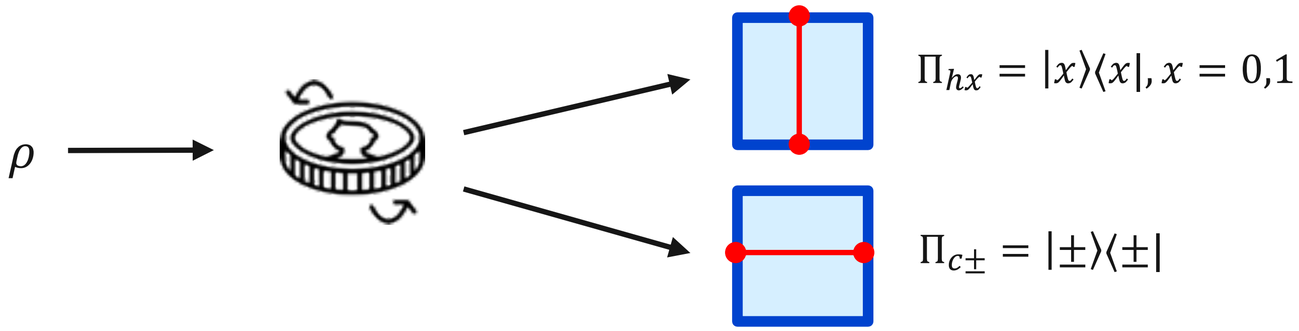
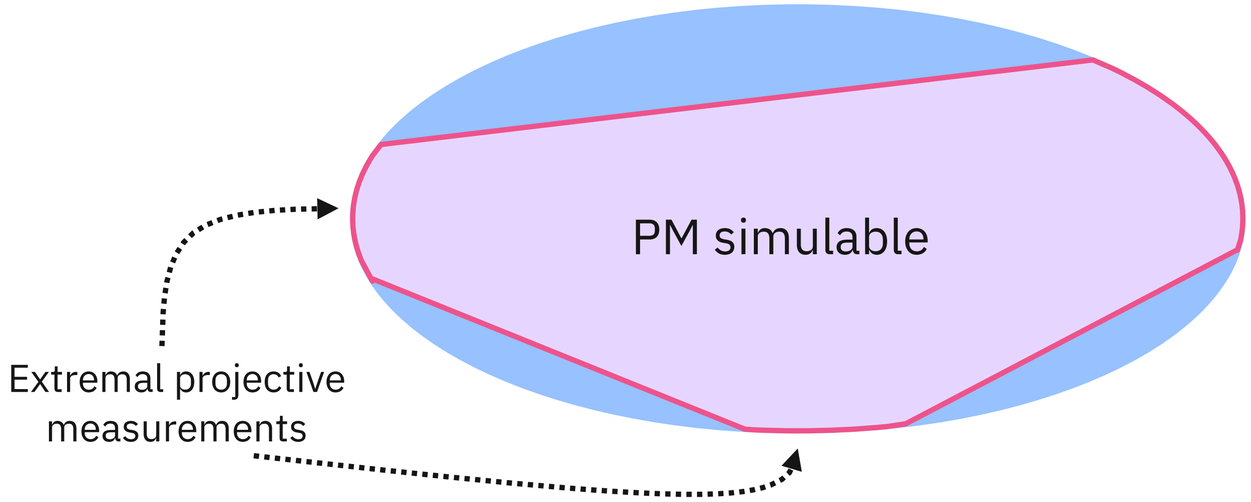
➢ Randomized implementation



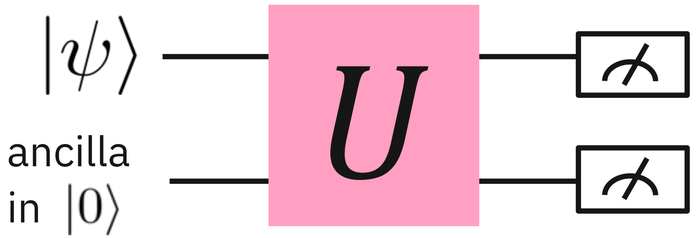
- No qubit overhead
- **Only valid for PM-simulable POVMs**



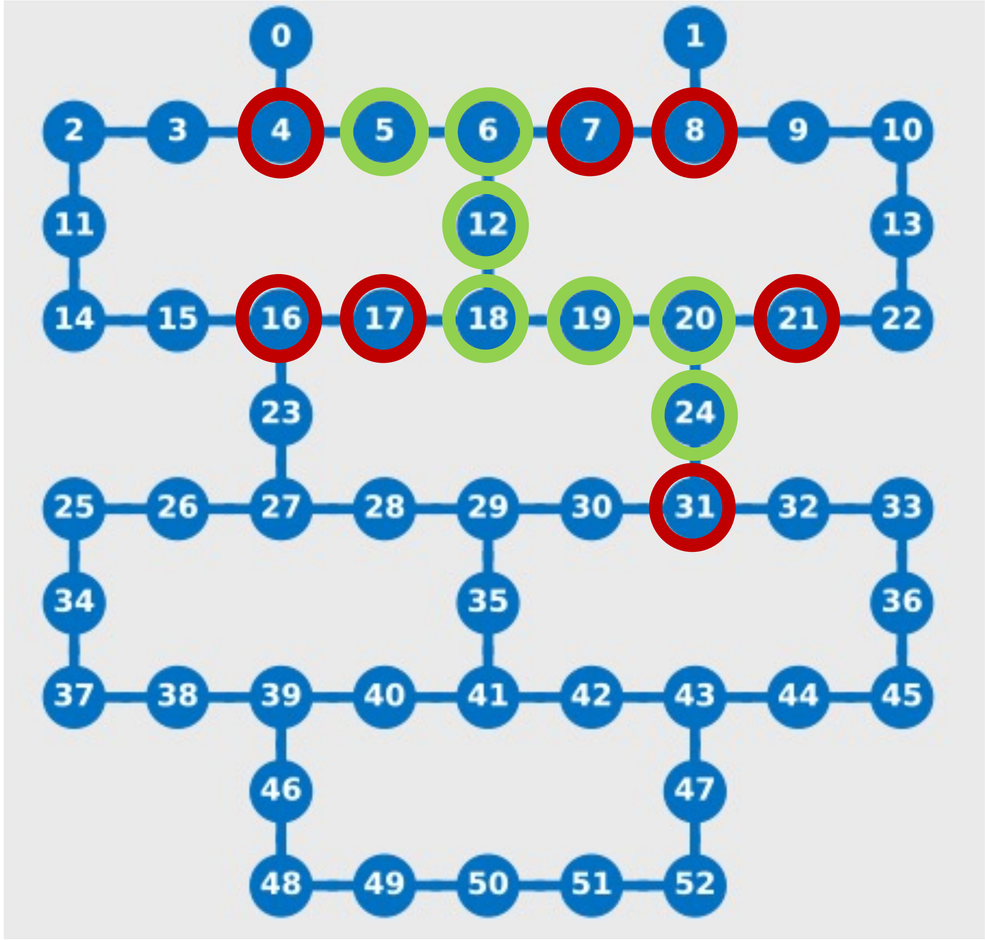
Using the dilation theorem

Naimark dilation theorem: Any POVM on a target system can be realized through projective measurements in a larger Hilbert space

- **"Tensor product"** implementation of POVM measurements through ancillas: $\mathcal{H}_A \otimes \mathcal{H}_B$



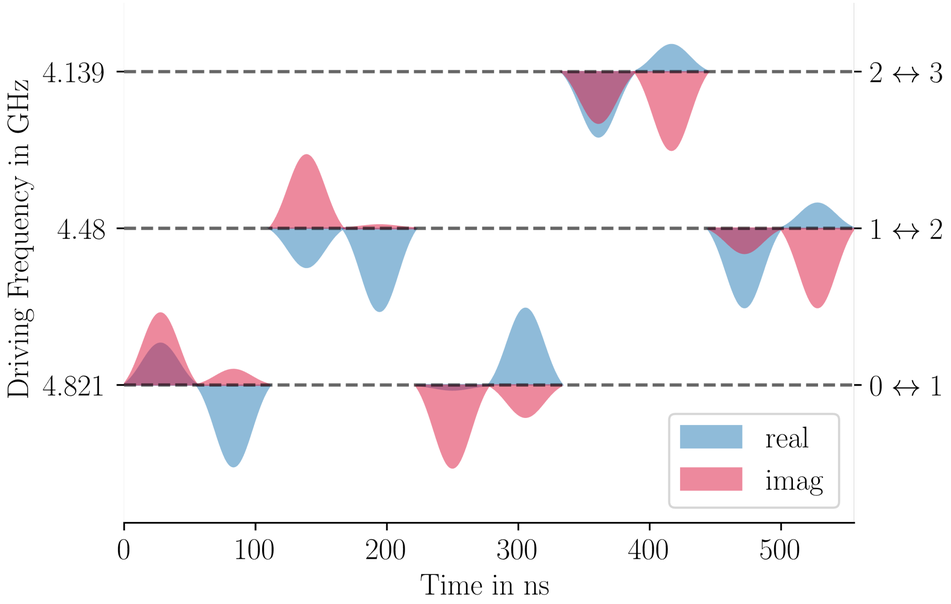
- **$2N$ qubits required**
- **Possible SWAP overhead** ($O(N^2)$ SWAPs with $O(N)$ depth in the worst case)

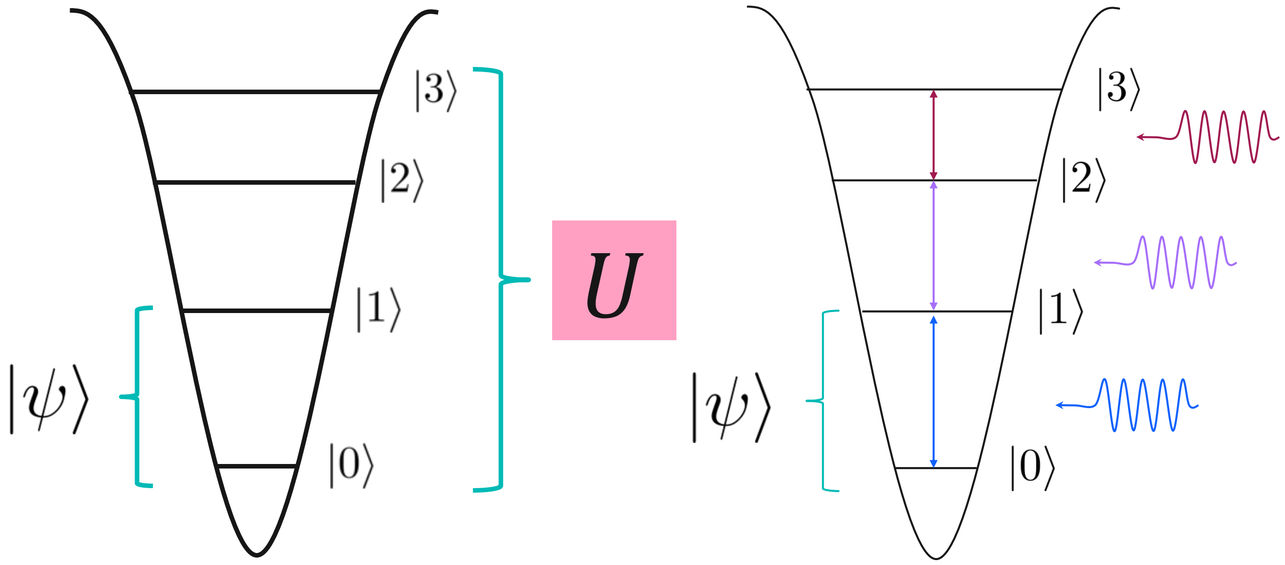


Using the dilation theorem on qudits

Naimark dilation theorem: Any POVM on a target system can be realized through projective measurements in a larger Hilbert space

- **"Direct sum"** implementation of POVM measurements with qudits:





Using superconducting qubits as anharmonic oscillators (can also be applied to other quantum computing architectures whenever qubits are embedded in larger spaces and extra degrees of freedom are accessible)

Only 3 types of physical pulses required
SX-01, SX-12, SX-23

Any 4-outcome 1-qubit POVM can be implemented with at most 10 pulses (plus some virtual Z gates)

L. E. Fischer et al., Phys. Rev. Resrearch 4, 033027 (2022)

Randomized IC-measurements in practice

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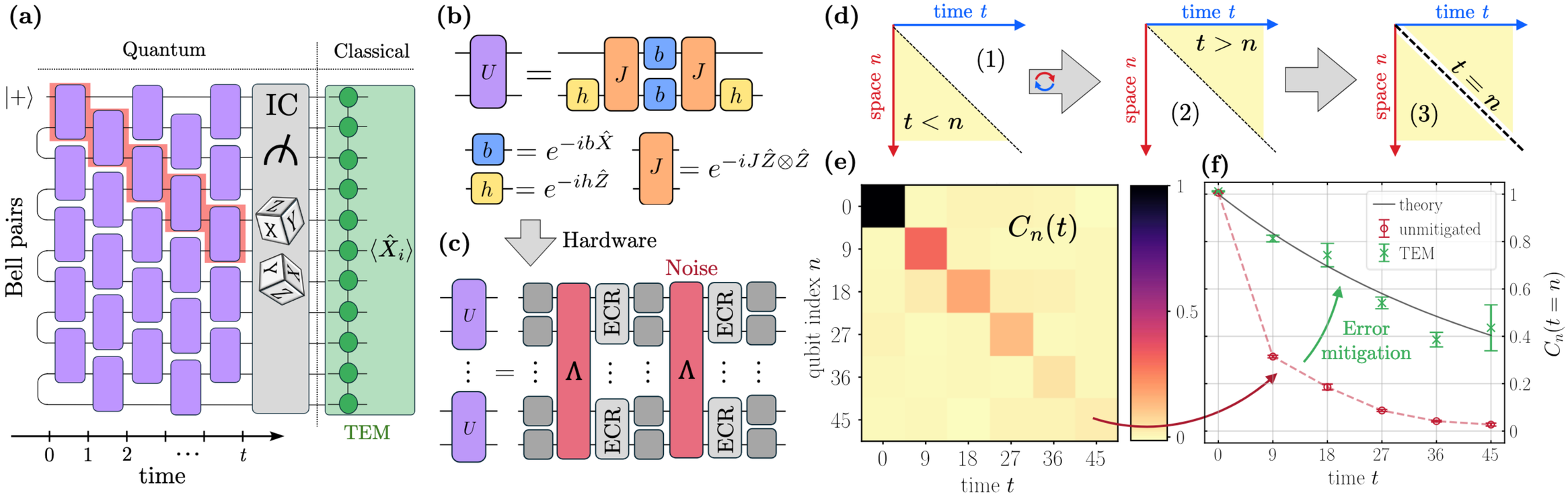

Dynamical simulations of many-body quantum chaos on a quantum computer

- Up to 91 qubits and 4095 2-qubit gates
- IC measurements & classical Tensor-Network based error mitigation
- 1kHz Sampling rate (twirling + randomized measurements)

L. E. Fischer, M. Leahy et al., arXiv:2411.00765

The Qiskit POVM toolbox

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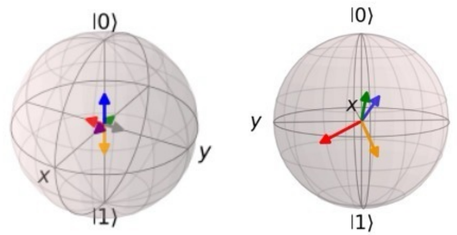
Theory

`povm_toolbox.library`

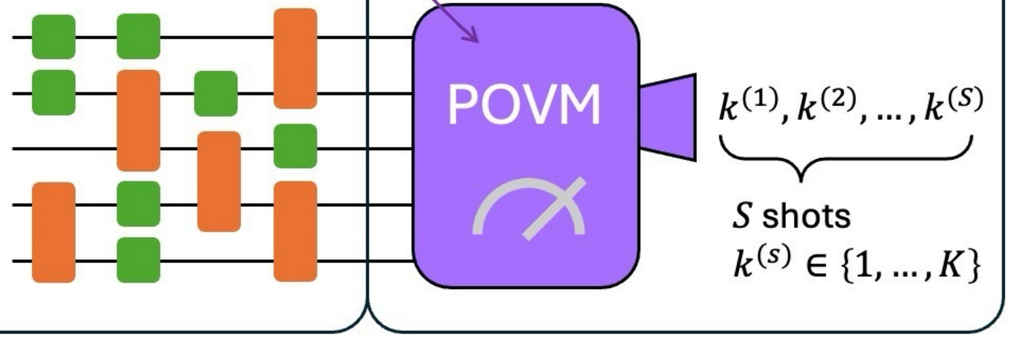
- Classical Shadows
- Randomized PVMs
- Dilation POVMs
- …

`povm_toolbox.quantum_info`



QPU

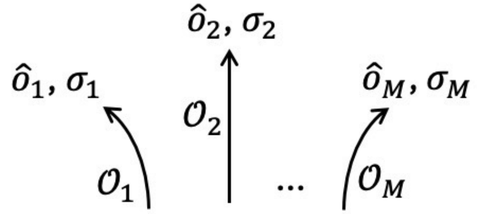
`povm_toolbox.sampler`



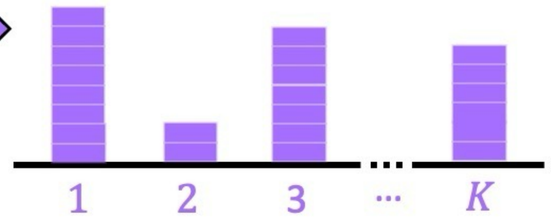
CPU

`povm_toolbox.post_processor`

$\hat{o}_i$: estimator of $\mathrm{Tr}[\mathcal{O}_i \rho]$
σ_i: standard deviation of $\hat{o}_i$



Estimate M observables



https://qiskit-community.github.io/povm-toolbox/