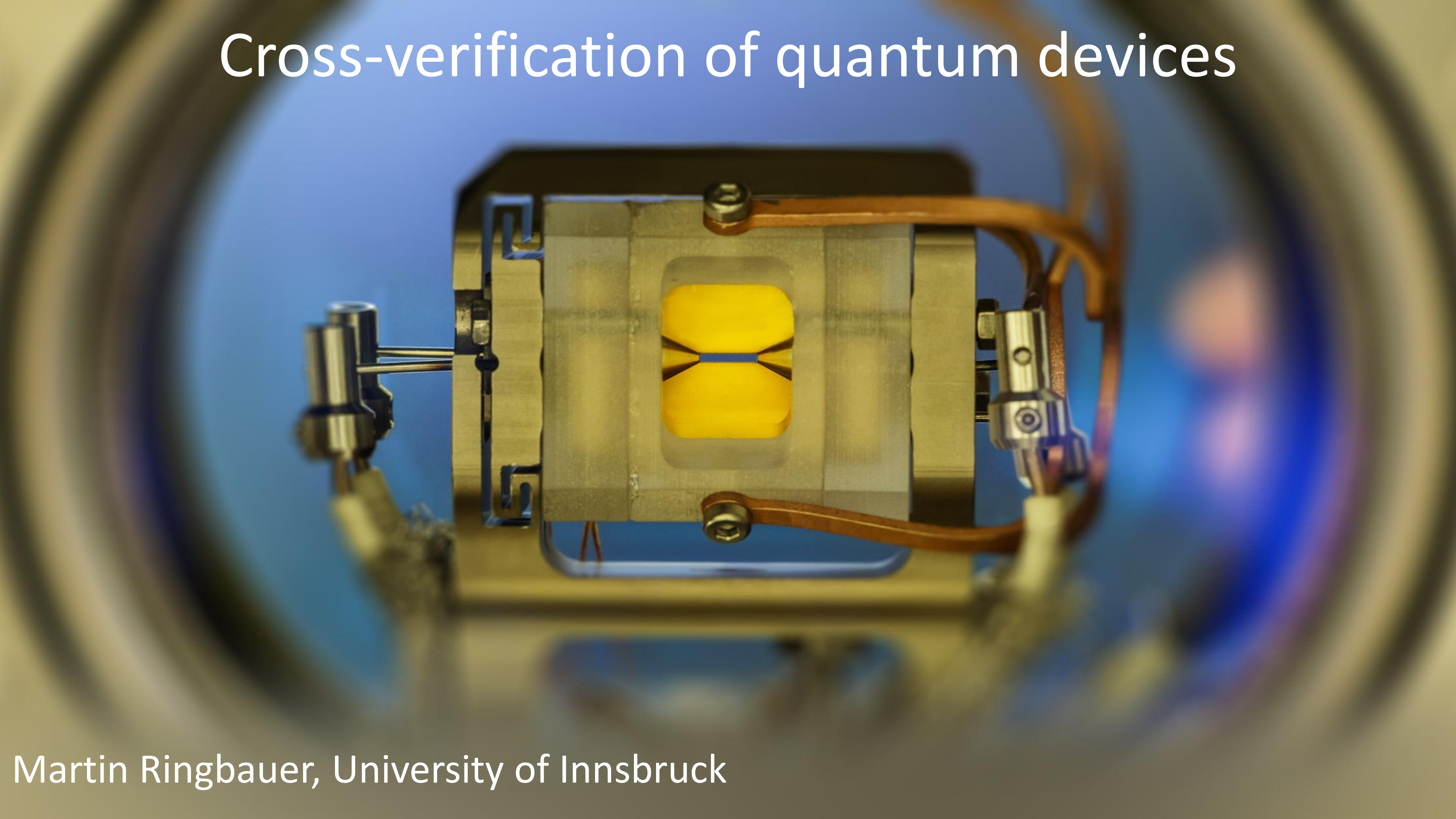
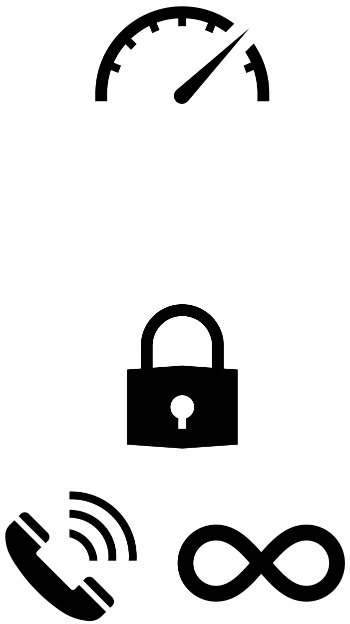
Cross-verification of quantum devices

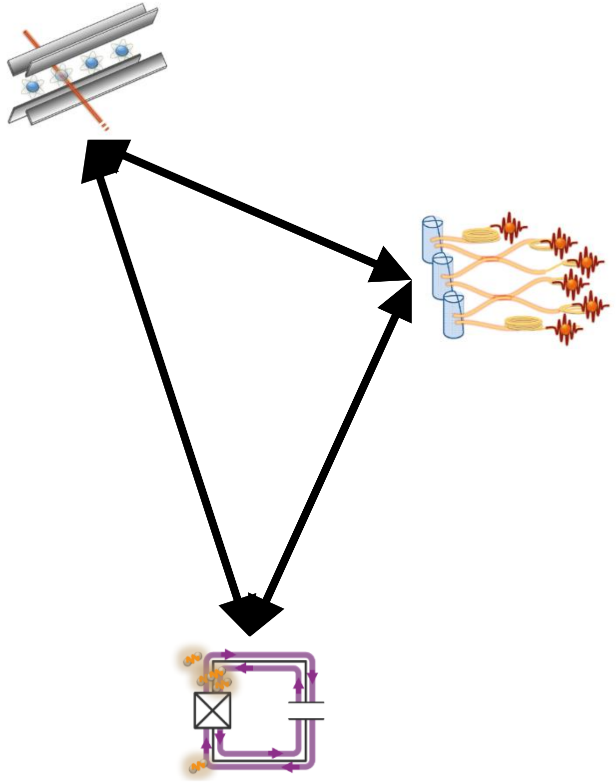


Martin Ringbauer, University of Innsbruck

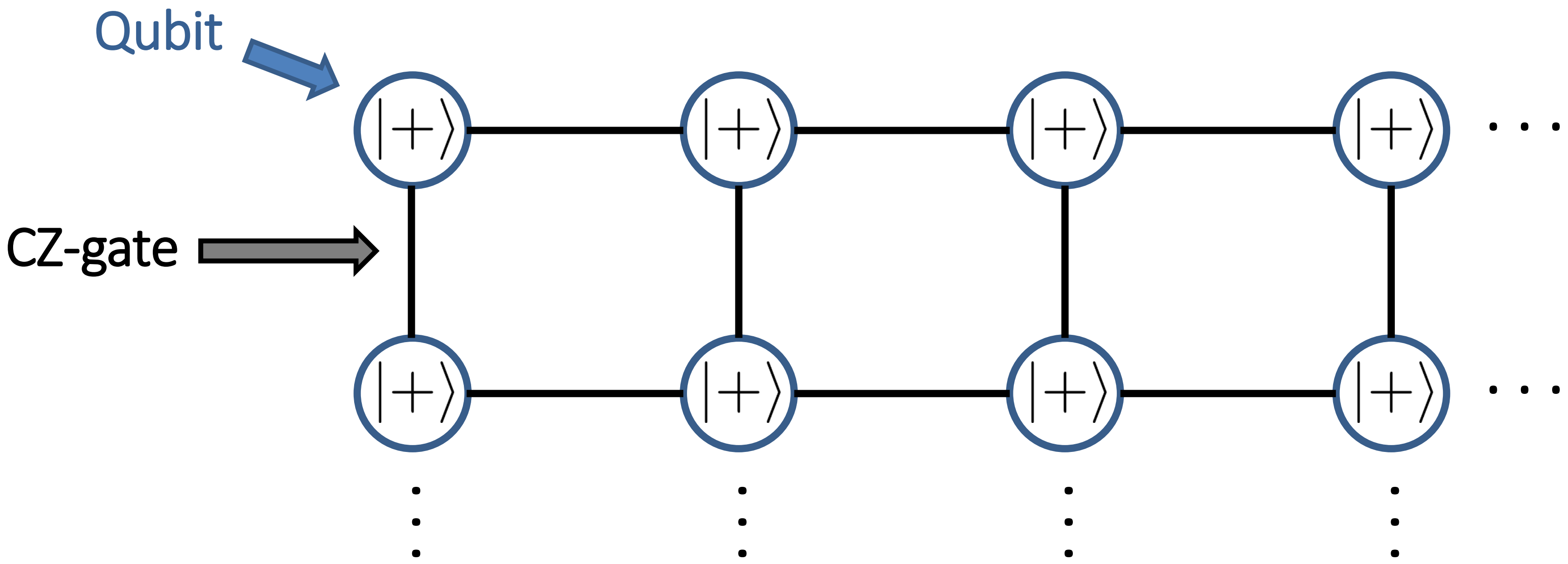
So you bought a quantum computer...



Credit: Dieter Kühl



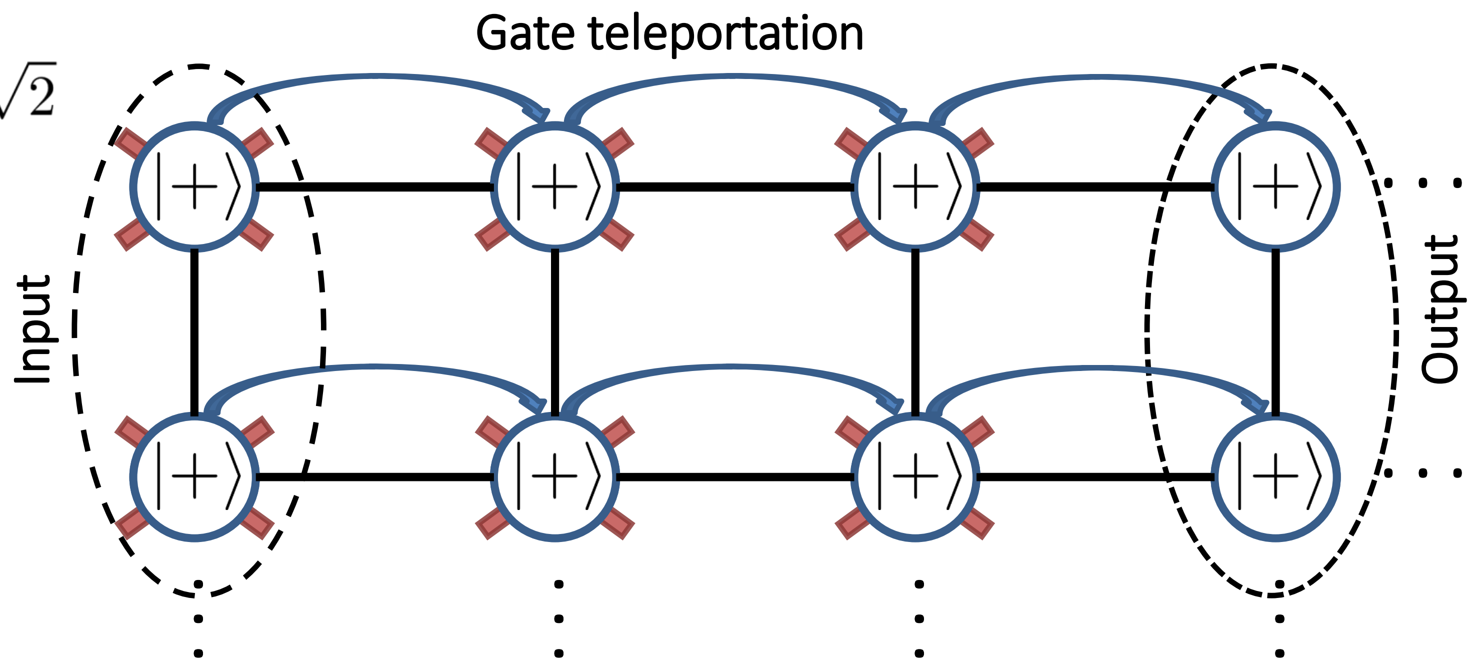
Measurement-based Quantum Computing



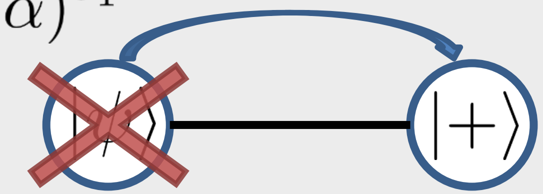
How do you compute with cluster states?

Measure:

$$(\langle 0| \pm e^{-i\alpha}\langle 1|)/\sqrt{2}$$



Error accumulation can be cancelled via feed-forward



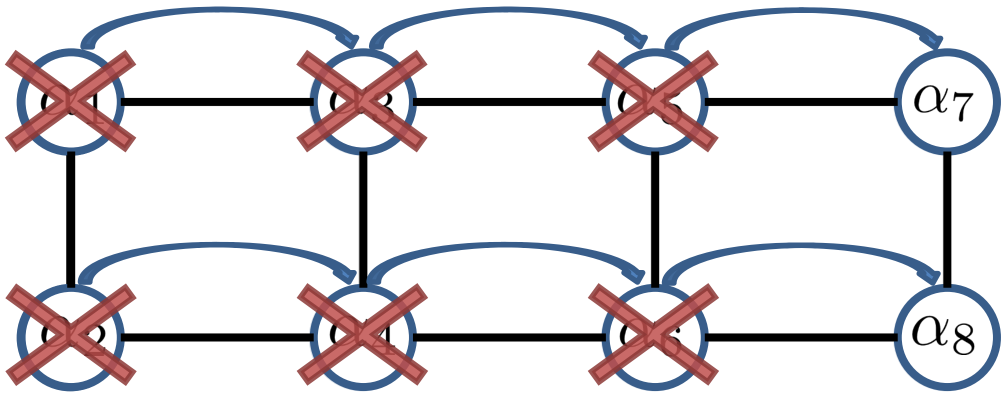
$$J(\alpha + s_1 * \pi)\,|\psi\rangle_2$$

$$J(\alpha) = H.Z(\alpha)$$

Universal set: $\{CZ, J(\alpha)\}$

Raussendorf, R & Briegel, HJ, Phys. Rev. Lett. 86, 5188 (2001)

Measurement-based Quantum Computing

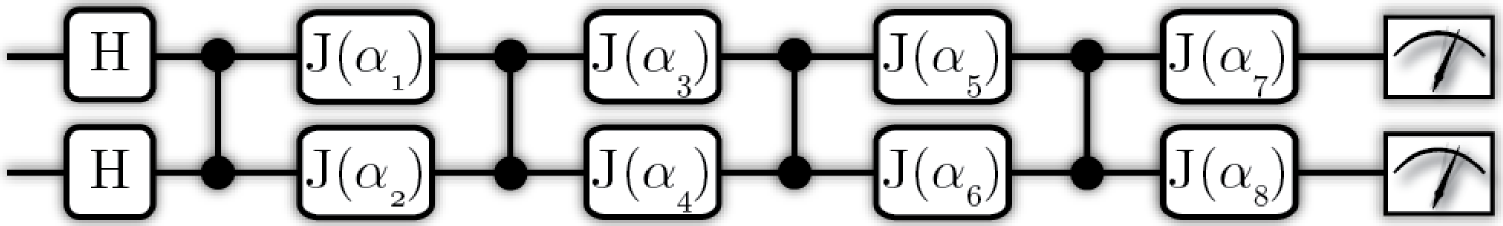


Important properties:

- Intermediate outcomes are uniformly random
- “Zero branch” corresponds to circuit
- Other branches correspond to different angles

$$J(\alpha) = H.Z(\alpha)$$

Universal set: $\{\mathrm{CZ}, J(\alpha)\}$



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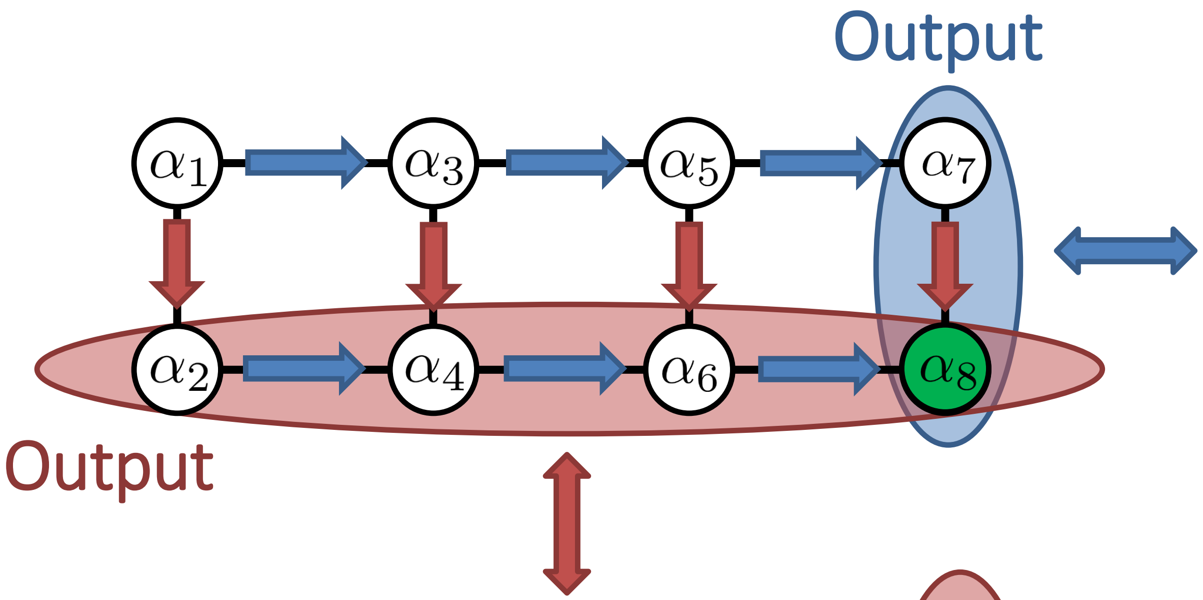
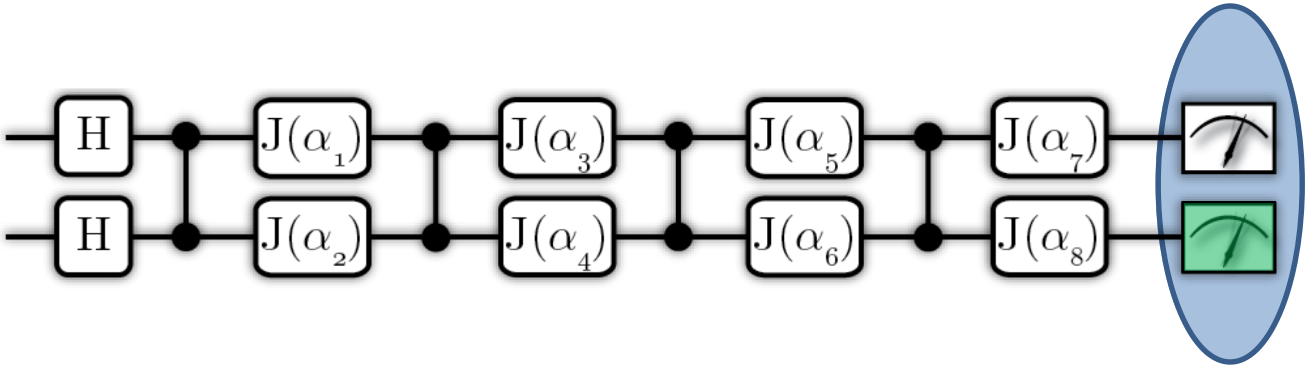
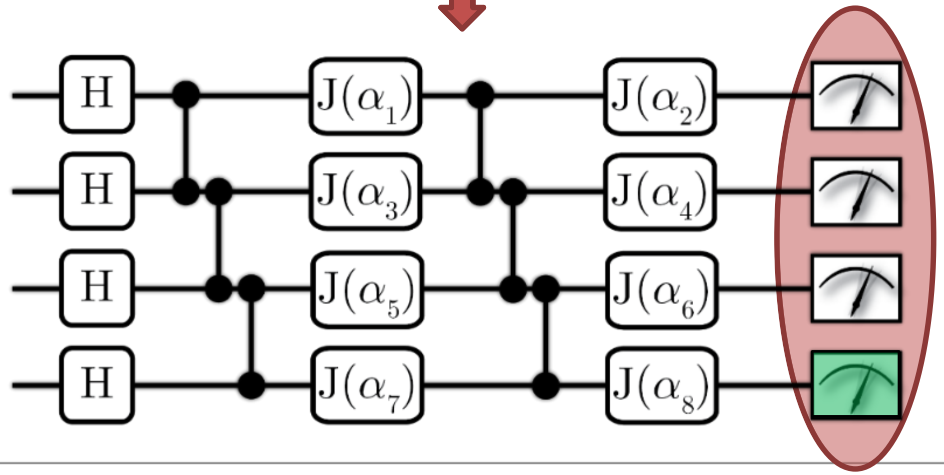
Same graph, different flow







The computations differ in

- input size
- depth
- structure
- (physical architecture)

...yet, certain outputs must agree
(can be randomized)

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arXiv: 1905.9790 (2019)

Cross-check protocol

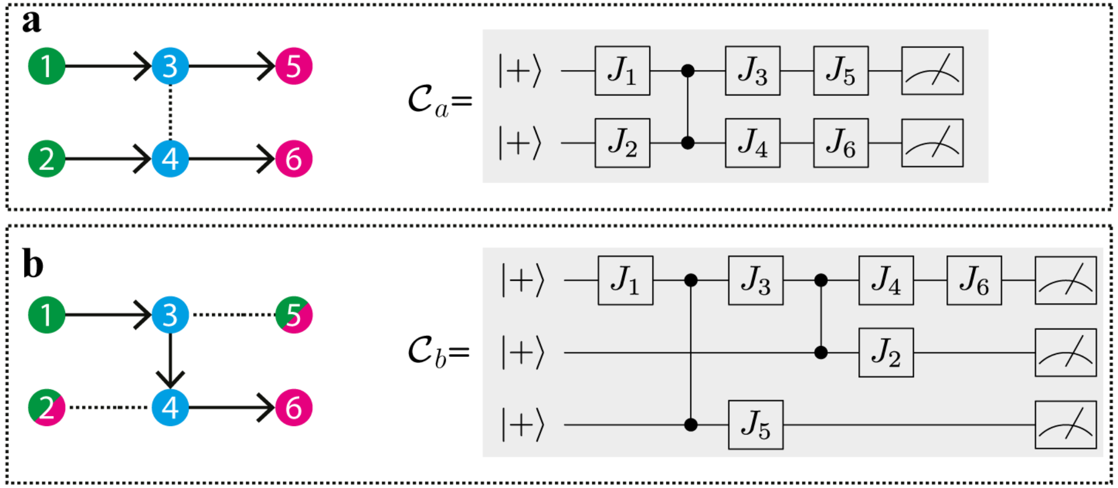
1) Pick a graph and derive two circuits.

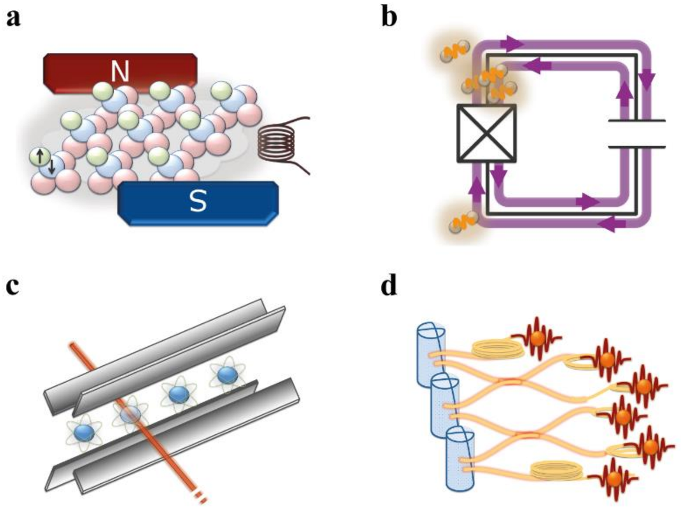
2) Pick angles $\{\alpha_1, \alpha_2, \alpha_3, \ldots\}$ + MBQC corrections.

3) Optionally mask the angles and outcomes.

4) Sample from the outputs of randomly chosen instances of the two circuits on different devices.

5) Estimate the “distance” between the output distributions.





arXiv: 1905.9790 (2019)

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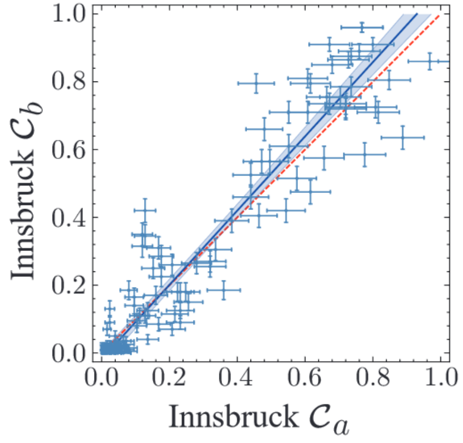
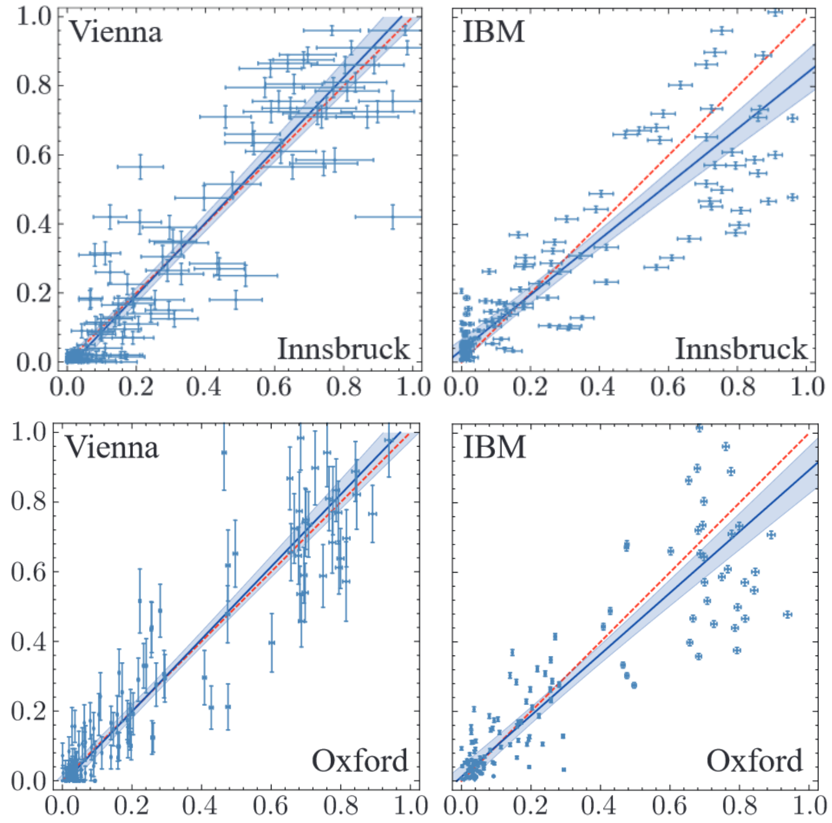
Non-scalable cross-checks

Randomly sampled MBQC-related computations on the same device



Randomly sampled MBQC-related computations on different devices



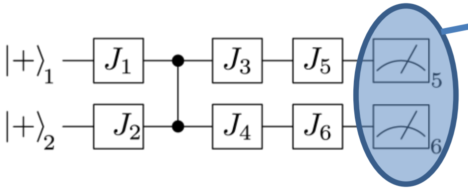
arXiv: 1905.9790 (2019)

(More) scalable cross-checks

Estimating output distributions is inefficient.
Instead estimate squared ℓ^2 distance between the output distributions

$\mathbf{p}_j$ = probability-vector for measurement strings over the <u>combined output set</u>

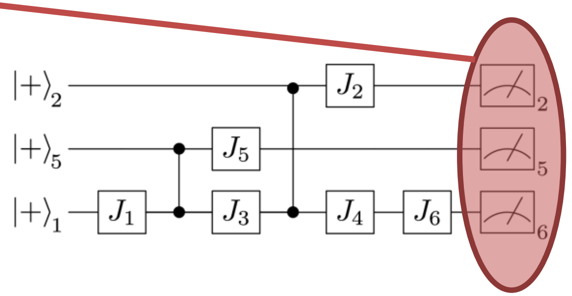
$$\|\mathbf{p}_1 - \mathbf{p}_2\|^2 = \mathbf{p}_1 \cdot \mathbf{p}_1 - 2\mathbf{p}_1 \cdot \mathbf{p}_2 + \mathbf{p}_2 \cdot \mathbf{p}_2$$



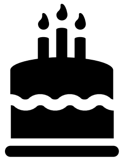
Scales as $\mathcal{O}(2^{n_{O_1}/2})$

Estimate as **collision probability** between output strings across the two devices

Scales as $\mathcal{O}(2^{(n_{O_1}+n_{O_2}-n_c)/2})$



Scales as $\mathcal{O}(2^{n_{O_2}/2})$



Knight, W. & Bloom, D. M. E2386. Am. Math. Mon. 80, 1141–1142 (1973)

arXiv: 1905.9790 (2019)

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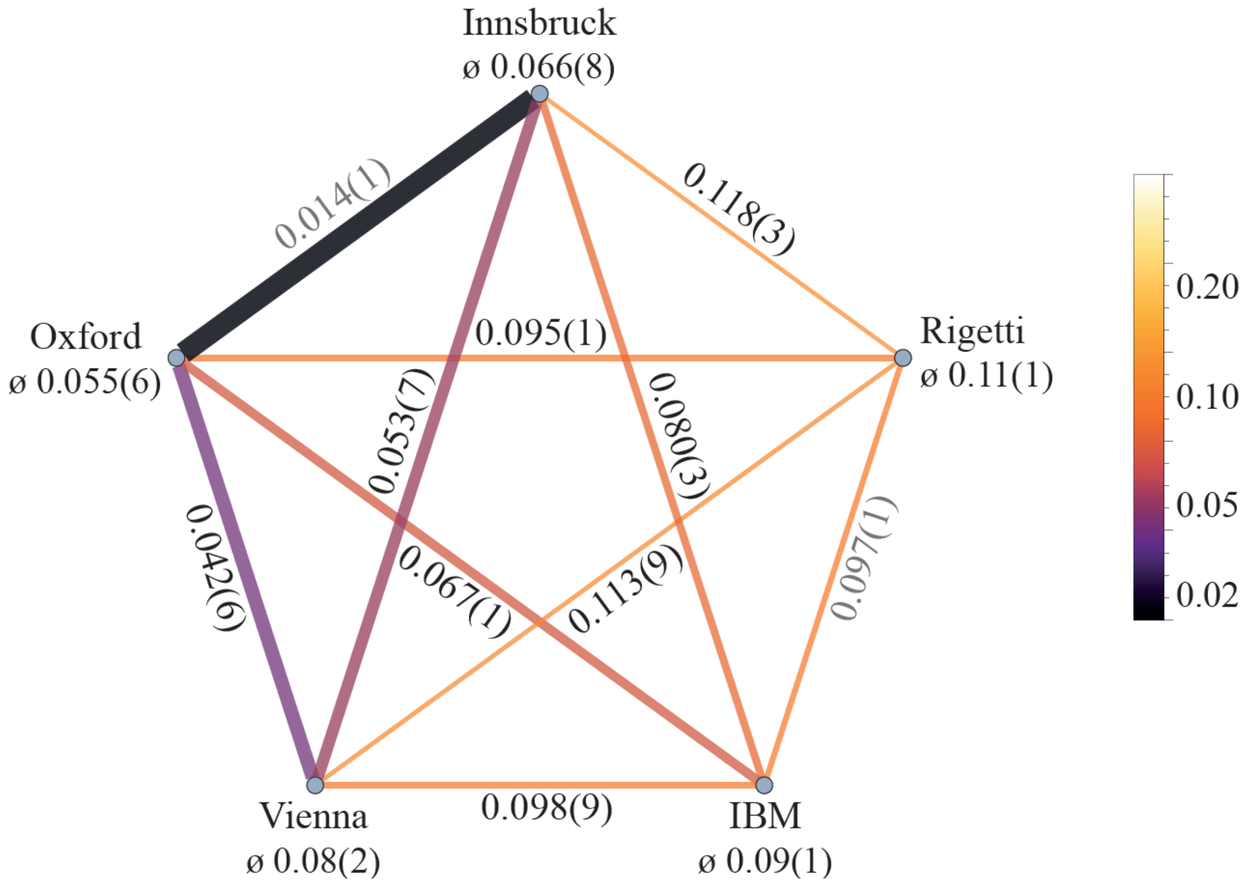
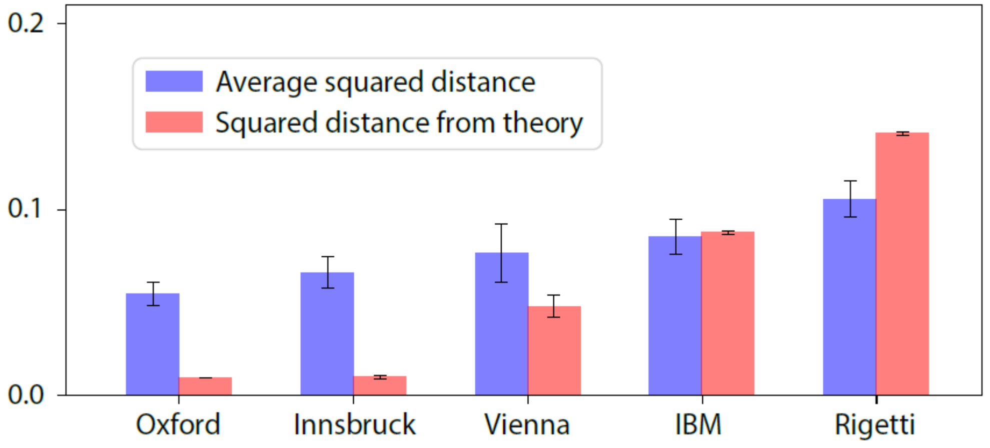
(More) scalable cross-checks

$$\|\mathbf{p}_1 - \mathbf{p}_2\|^2 = \mathbf{p}_1 \cdot \mathbf{p}_1 - 2\mathbf{p}_1 \cdot \mathbf{p}_2 + \mathbf{p}_2 \cdot \mathbf{p}_2$$



		3-qubit		6-qubit
		IBM	Rigetti	Vienna
2-qubit	Oxford	0.067(1)	0.095(1)	0.042(6)
	Innsbruck	0.080(3)	0.118(3)	0.053(7)
6-q.	Vienna	0.098(9)	0.113(9)	



arXiv: 1905.9790 (2019)

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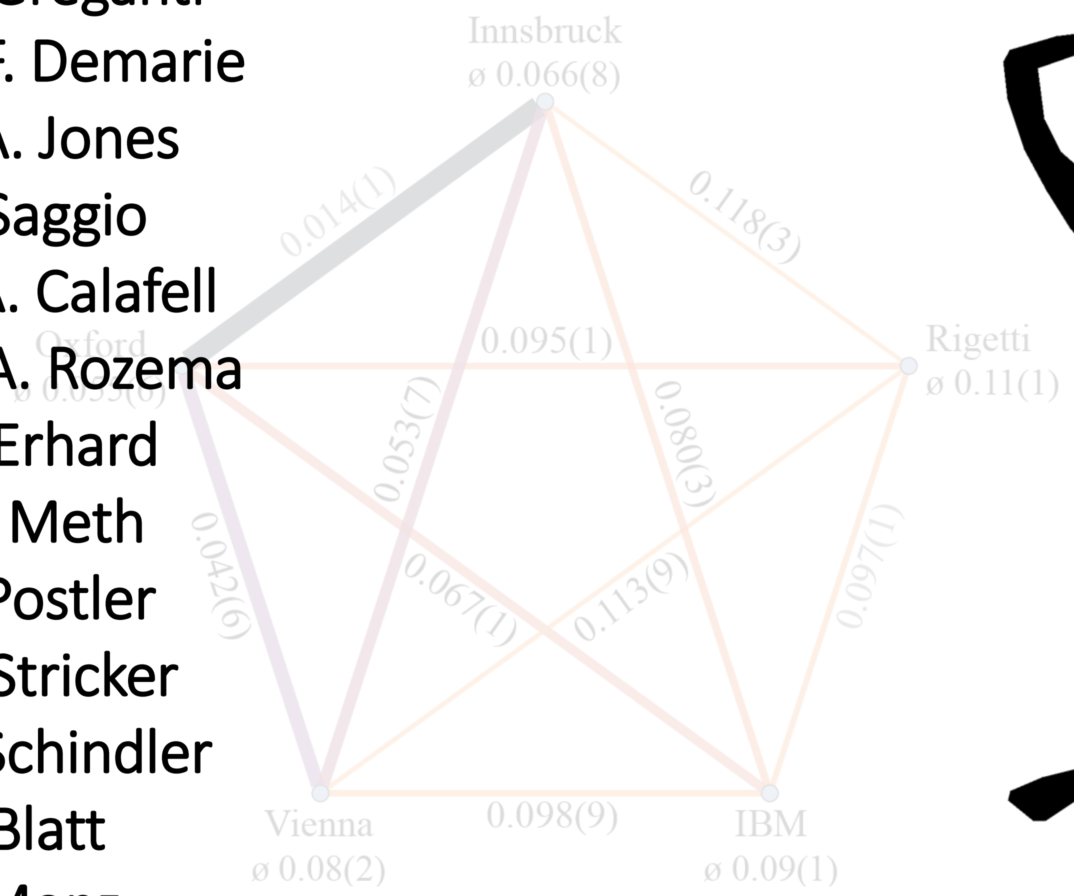
Scalable cross-validation

$$\|\mathbf{p}_1 - \mathbf{p}_2\|^2 = \mathbf{p}_1 \cdot \mathbf{p}_1 - 2\mathbf{p}_1 \cdot \mathbf{p}_2 + \mathbf{p}_2 \cdot \mathbf{p}_2$$

C. Greganti
T. F. Demarie
J. A. Jones
V. Saggio
I. A. Calafell
L. A. Rozema
A. Erhard
M. Meth
L. Postler
R. Stricker
P. Schindler
R. Blatt
T. Monz
P. Walther
J. F. Fitzsimons



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