Qiskit | Community Summer Jam

DEVICE-INDEPENDENT TESTS FOR QUANTUM NETWORKS

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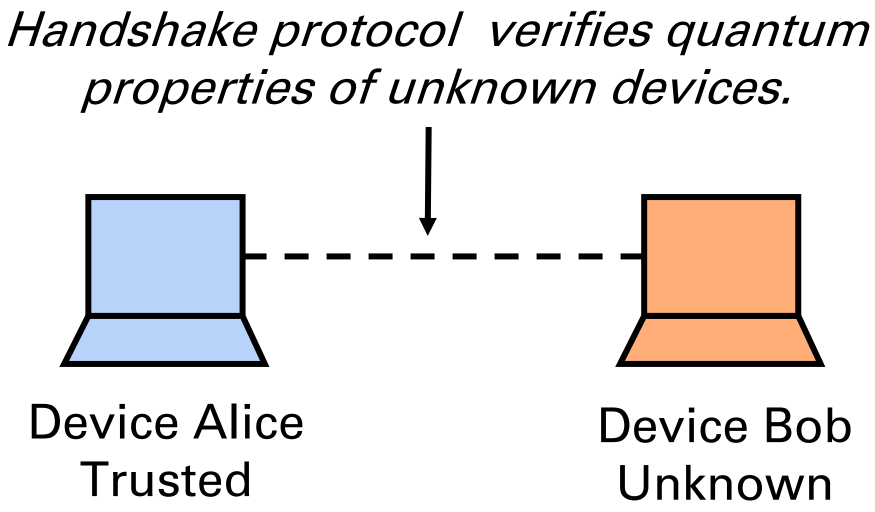
Motivation

1. Quantum networks enable technologies like teleportation and quantum key distribution to be deployed at scale.
2. Quantum communication protocols require authentic quantum properties. *A priori*, it is difficult to characterize and trust the quantum capabilities of an unknown device.
3. A handshake protocol is required to certify the "quantumness" of unknown devices.

Establishing Quantum Network Connections



What We Accomplished

1. Developed a device-independent handshake protocol that verifies quantum systems.
   - Tests dimension, superposition, incompatible measurements, and entanglement.
   - Protocol is generic and could run on future quantum networks of any design.
2. Prototyped and tested handshake protocol with Qiskit.
   - Tested on real quantum devices.
3. Project Website:
   - Outline of general device-independent handshake protocol.
   - Runnable code examples of our quantum verifying test suite.
   - Technical documentation of device-independent testing theory and software.

Device-Independent Test

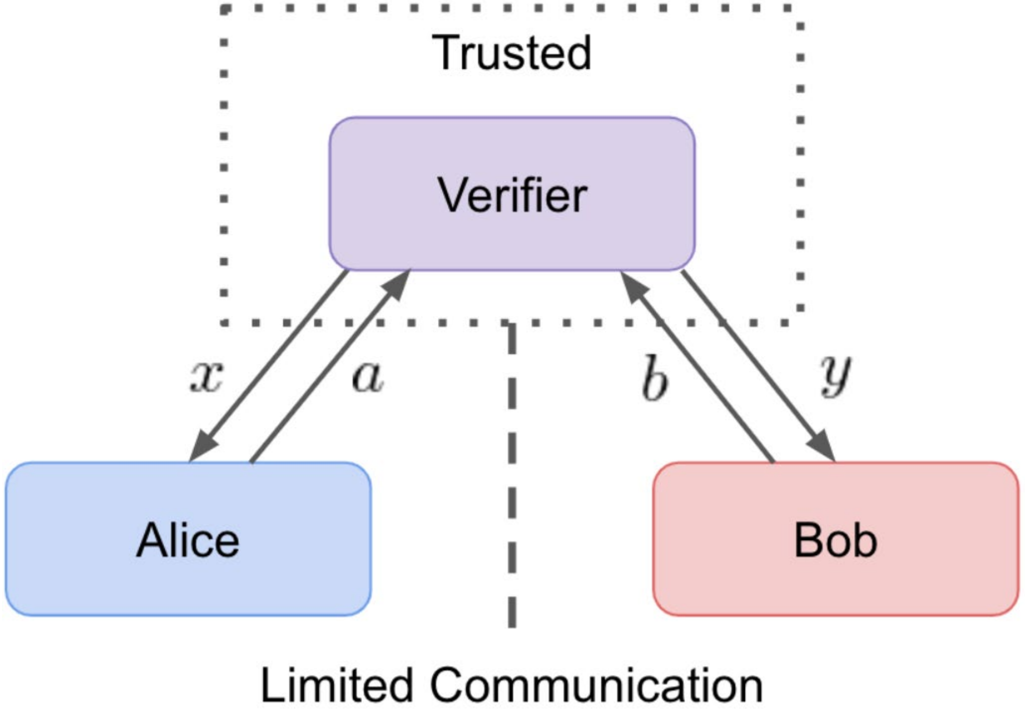
Certifies the quantum properties of unknown systems without knowledge of the underlying physics.

Key Assumption:

- There is limited quantum and classical communication between Alice and Bob.

Framework:

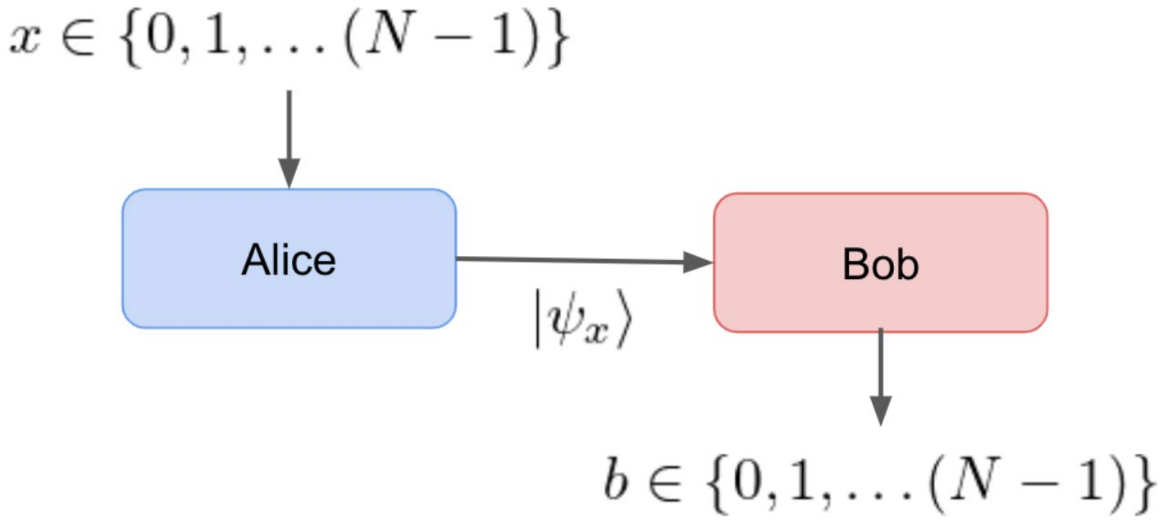
1. The Verifier sends inputs *x* and *y* to devices Alice and Bob.
2. Alice and Bob compute results *a* and *b* and return the value to the Verifier.
3. The Verifier ascertains quantumness using the conditional probability distribution *p(ab|xy).*



Verifying Hilbert Space Dimension

Test: Classical Dimension

- Alice receives input *x* and encodes it into computational basis states.
- Bob measures the quantum state in the computational basis and outputs *b*.
- The dimension of the quantum state bounds Bob's success probability, *Psucc*.
- Quantum and classical share the same dimensional bound.
- Verifies Hilbert space dimension of quantum and classical states.



$$\frac{d}{N} \geq p_{\text{succ}} = \frac{1}{N} \sum_{x=0}^{N-1} p(b = x|x),$$

Bob's success probability is bounded by the Hilbert space dimension *d*.

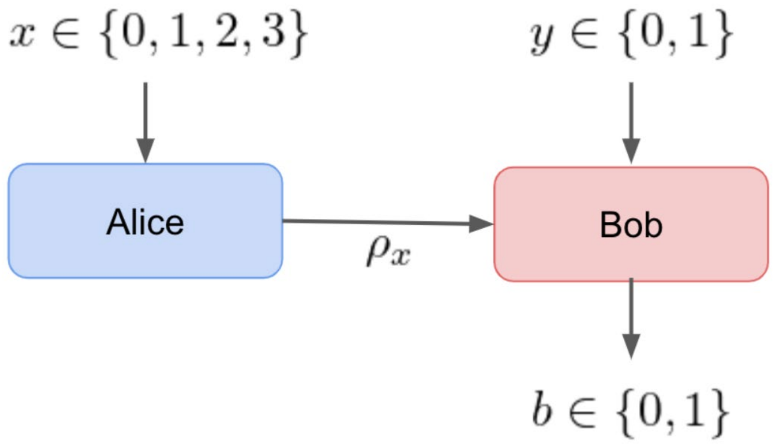
Verifying Incompatible Measurements

Measurement incompatibility

- Incompatible measurements give rise to quantum Bell violations: quantum statistics classical systems cannot achieve.

Test: Single-Qubit Bell Violation

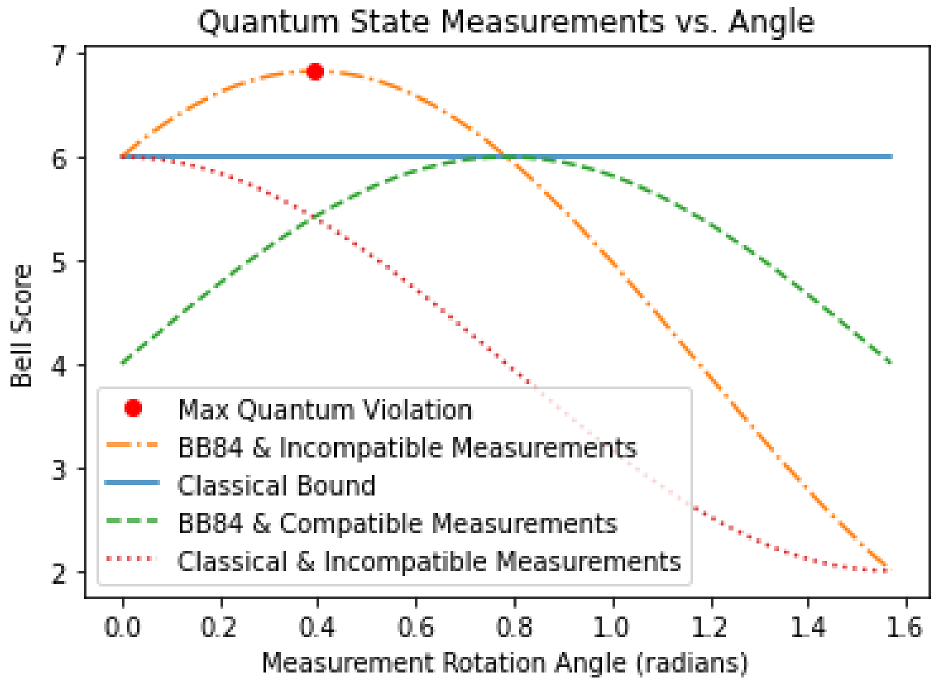
1. Alice encodes ***x*** into the BB84 qubit states.
2. Bob performs a set of incompatible measurements conditioned on ***y*** and outputs result ***b***.



- Classical bound

$$p(0|00)+p(1|10)+p(0|20)+p(1|30)$$
$$+\,p(1|01)+p(0|11)+p(0|21)+p(1|31)\leq 6$$

- Quantum violation
  - Maximal quantum violation at 6.818



Verifying Entanglement – CHSH inequality

Entanglement

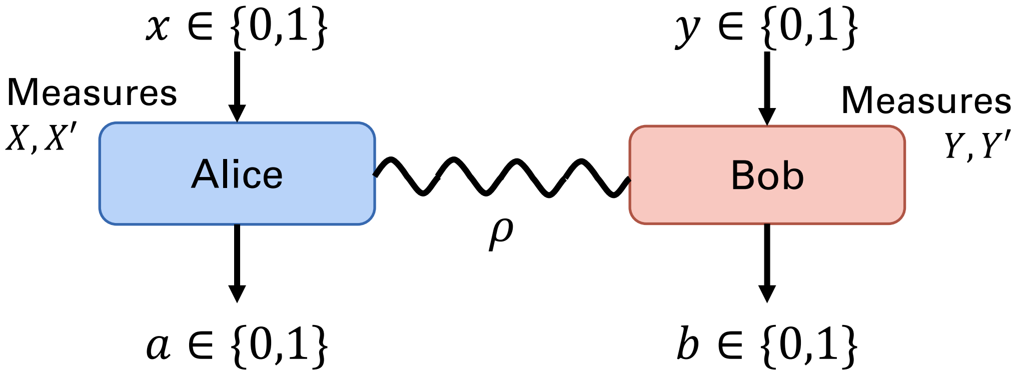
- "Spooky action at a distance"
- An essential resource in quantum communication

Classical bound

- No entanglement or quantum measurement

$$|\langle XY\rangle + \langle X'Y\rangle + \langle XY'\rangle - \langle X'Y'\rangle| \leq 2$$

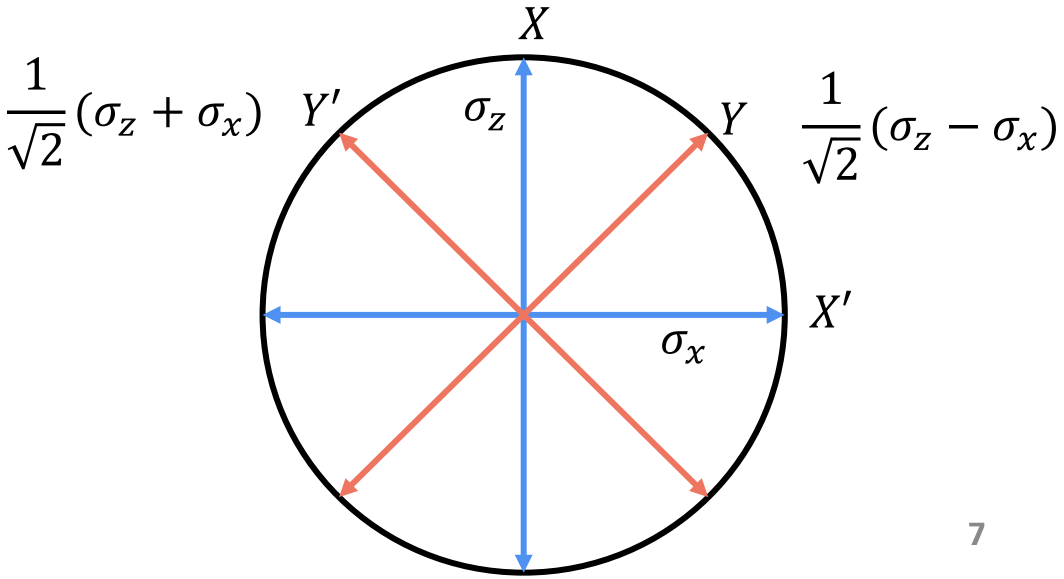
Test: CHSH Violation



Alice and Bob each performs a two-outcome measurement according to their inputs

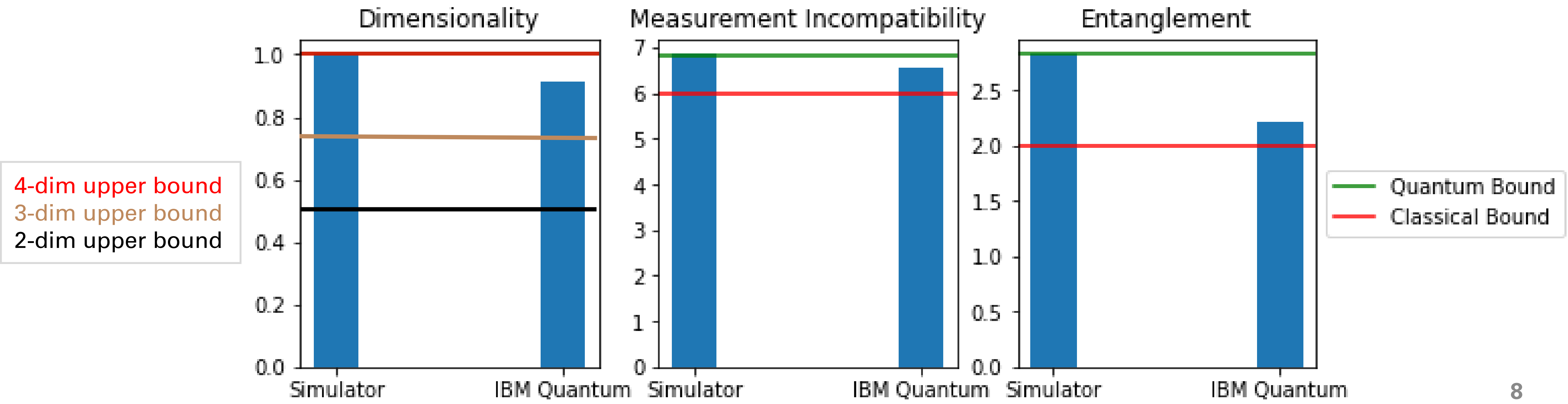
Quantum violation

$$|\langle XY\rangle + \langle X'Y\rangle + \langle XY'\rangle - \langle X'Y'\rangle| = 2\sqrt{2} \not\leq 2$$



Testing on IBM Quantum Computers

- Not an ideal test as Alice and Bob run on the same device.
- No assumptions about limited communication can be made.
- 8,592 shots on ibmq_16_melbourne



Future Works

- Additional device-independent tests, such as gate tomography test quantum dimensionality witnessing, higher dimensionality, etc.
- Adherence to/creation of standards for quantum networking
- Testing with real quantum networks
- Handshake protocol for calibrating and securing connections between devices
- Tests for multi-partite networks

Conclusion and Outlook

- Designed a handshake protocol for verifying unknown quantum devices.
- Prototyped protocol in Qiskit and ran on IBM quantum computers:
  - GitHub: https://github.com/ChitambarLab/QiskitSummerJam2020
- Project documentation:
  - Website: https://chitambarlab.github.io/QiskitSummerJam2020/index.html