Violating Bell's Inequality with Single-Photon Entangled States using Self-Referential Measurements

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In the early 1990s, it was suggested that a single photon split into two spatial modes could violate a Bell inequality [1], [2]. Previous implementations relied on local oscillators, raising concerns about the true origin of the correlations [3], [4], [5]. We demonstrate a CHSH violation without the need for local oscillators or post-selection, using two copies of a single-photon entangled state. Two indistinguishable photons are split on beam splitters and shared between Alice and Bob. In our self-referential scheme, one copy acts as the phase reference for the other.

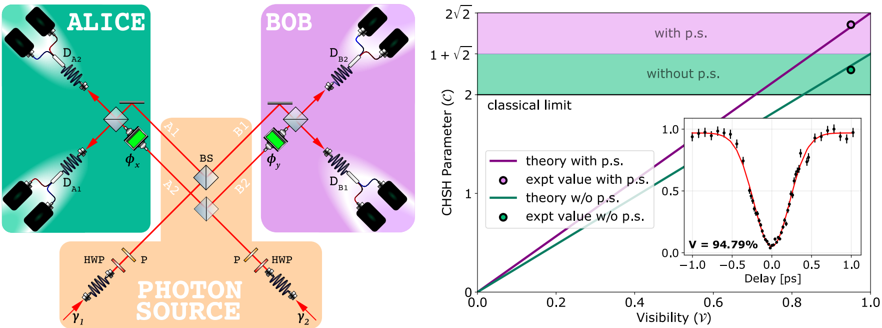

Fig. 1: Setup: Two identical photons are split and distributed to Alice (blue) and Bob (green), who apply local phases and interfere modes for joint detection. Results: We observe CHSH violations of 2.25 ± 0.02 (no post-selection) and 2.71 ± 0.03 (with post-selection), with 95% Hong-Ou-Mandel visibility, close to theoretical maxima.

We achieve a Bell violation above the classical bound using two copies of separable single-photon states, reaching 2.25 ± 0.02 without and 2.71 ± 0.03 with post-selection. This provides a simpler, oscillator-free route to device-independent quantum cryptography, where Bell violations certify secure correlations between distant parties.

References

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