”Quantum spookiness“ at zero distance

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Quantum contextuality generalizes Bell experiments to systems without space-like separation. I will present two experiments in which we demonstrate such non-classical correlations in a local system - a single trapped ion qutrit.
In the first experiment [1], we violate the 5-observable KCBS inequality [2], which is arguably the most fundamental non-contextuality inequality for testing Quantum Mechanics (QM) (Fig. 1).

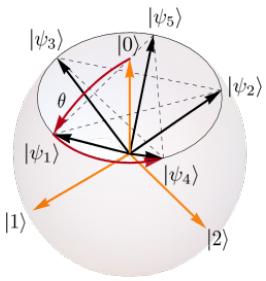

Figure 1: ”Qutrit sphere” of superposition states with real coefficients. In KCBS, measurements are performed along $N = 5$ directions on a pentagon, as shown.

By systematically characterizing and scanning systematic effects, we violate classical predictions by up to 25 standard deviations, while remaining in agreement with QM predictions. We show that the QM bound of the KCBS inequality is within experimental reach, and that values of correlations beyond those available to Bell tests are resolvable.

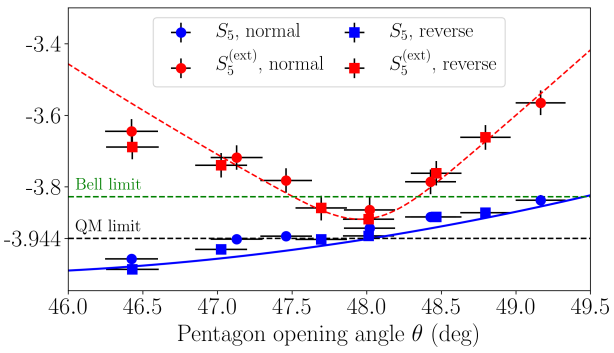

Figure 2: Experimental measurements of the KCBS witness together with theoretical predictions. The blue points are the traditional witness, while the red points include compensation for observed signaling.

The KCBS inequality can be extended into scenarios with $N > 5$ observables. In analogy to chained Bell inequality tests, increasing the number of observables can be used to increase the amount of computational power available in the system, as measured by the Contextual Fraction (CF). While chained Bell inequalities have been violated for up to $N = 90$ observables, current studies on the extended KCBS scenario, where even stronger correlations are possible, were limited to $N = 7$. We present measurements of the extended KCBS inequality with up to $N = 121$ observables, finding violations of classicality in all prepared scenarios up to $N = 101$ observables. We observe an increase in the contextual fraction up to a value of $0.800(4)$ for $N = 31$, above which experimental imperfections result in decreasing values.

In the second experiment [3] we study the state-independent contextuality inequality by Yu and Oh [4]. We use a novel state-recycling scheme, where measurements are randomly drawn from the Yu-Oh set (Fig. 3) and applied to the exiting state. We perform a sequence of 53 million

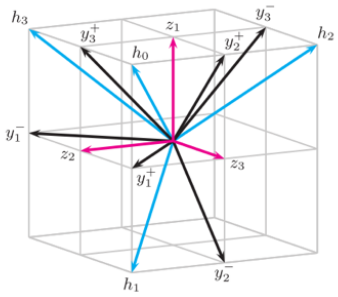

Figure 3: ”Qutrit cube” of superposition states with real coefficients. In the Yu-Oh experiment, every measurement is randomly selected to be along one of the 13 directions shown.

measurements of a single qutrit, violating the optimal state-dependent inequality by 214 standard deviations. This is done without re-initializing the state and with measurement directions selected on the fly by a quantum random number generator.

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[3] F. M. Leupold, M. Malinowski, C. Zhang, A. Cabello, J. Alonso and J. P. Home, arXiv:1706.07370 (2017).

[4] S. Yu and C. Oh, Phys. Rev. Lett. 108, 030402 (2012).