Experimental test of quantum causal influences

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Abstract

Understanding cause-effects relations among phenomena is a pivotal task in several sciences. The simplest scenario to estimate the direct causal influence between two variables, without resorting to interventions on the underlying mechanism generating the correlations, is the instrumental process. This is shown in Fig. 1, where circles stand for random variables and arrows for causal links. Analogously to the better-known Bell scenario, the correlations among the variables involved in this process satisfy testable constraints (instrumental inequalities), which, if violated, can detect the presence of non-local correlations. However, this is possible only when the variable X takes three or more values. Instead, when all variables are binary, no inequality is known. Nonetheless, a novel strategy to detect non-local phenomena has been recently introduced [1], based on quantifying direct causal influences among the variables through interventions (Fig. 1b).
In our work [2], we implement this method exploiting a photonic platform equipped with an active feed-forward of information. Moreover, our setup allows fast switching between two different causal scenarios, namely the observational and the interventional instrumental scenario. Our results demonstrate a novel way to detect non-classical correlations, which goes beyond standard Bell-like inequalities, and thus might lead to new insights in quantum causality and practical applications.

References

[1] M. Gachechiladze, N. Miklin, and R. Chaves, Physical Review Letters, vol. 125, no. 23 (2020) p. 230401
[2] I. Agresti et al., Science Advances, vol. 8, issue 8 (2022) eabm1515

Figures

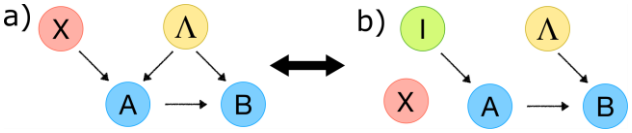

Figure 1: a) Observational and **b)** interventional instrumental scenario.

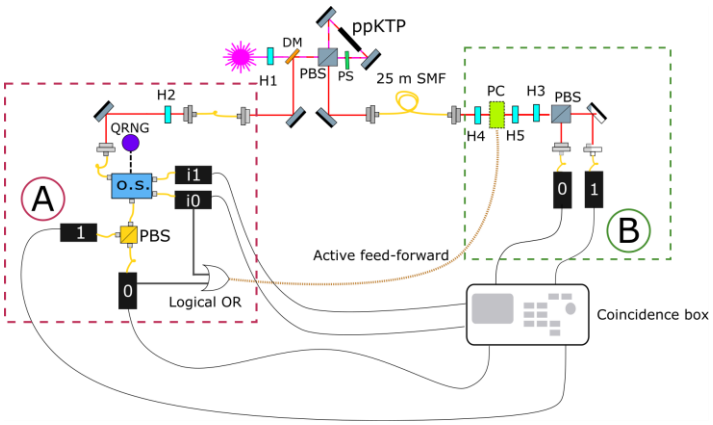

Figure 2: Experimental setup. H1,H2,H3,H4,H5 = half-wave plates; DM = dichroic mirror; PS = phase-shifter; SMF = single-mode fiber; QNRG = quantum random number generator; PBS = polarizing beam splitter; PC = Pockels cell.