Direct Detection of Quantum Superposition at a Distance

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In this work, we realise an operational procedure to distinguish a classical mixture from a quantum superposition through an XOR quantum communication game [1]. The task is to determine the effect of an intervention made by a referee on two (superposed) paths without re-interfering them (see Fig. 1). In Ref. [1] the referee was given beam blockers, resulting in a predicted probability to win (P_{win}) of 9/16 for a quantum superposition, whilst for a classical mixture P_{win} is 1/2. In this work, we show that by replacing the beam blockers with phase shifters, we can increase the predicted quantum P_{win} to 3/4. We experimentally implement this task using photon pairs from a Spontaneous Parametric Down-Conversion (SPDC) source and achieve an experimental P_{win} = 0.696 ± 0.009, well above the classical limit. Additionally, we contrast the quantum and classical cases by varying the mixedness of the source particle from a pure state to a fully mixed state and find strong agreement with the theoretical predictions (see Fig. 2). Finally, our work shows that this procedure not only allows us to observe the presence of a coherent superposition but also to extract the value of the relative phase between two paths without interfering them.

References

[1] F. del Santo and B. Dakić, PRL, 124 (2020)

Figures

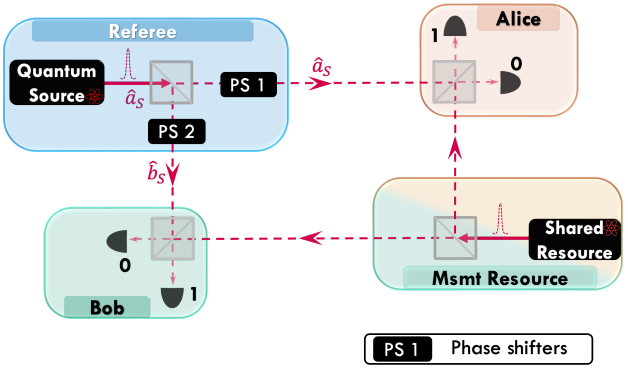

Figure 1: Schematic of XOR game setup. The referee provides an unknown resource (classical or quantum) and challenges Alice and Bob to output the parity of the presence (1) or absence (0) of his phase shifters, PS1 and PS2 (XOR game).

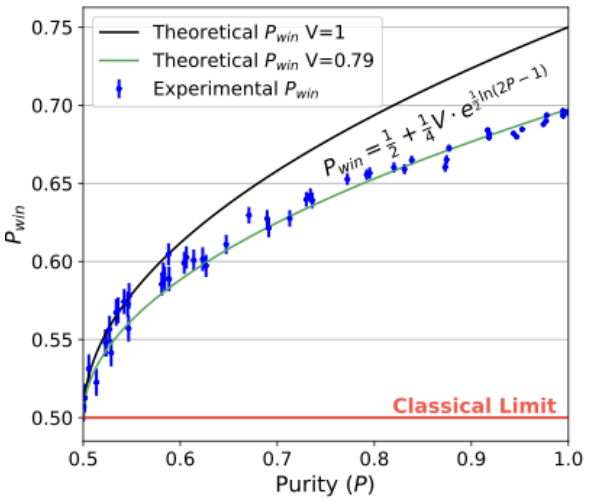

Figure 2: Transition from classical case (P_{win} = 1/2) to the quantum case (3/4 ≥ P_{win} ≥ 1/2) with increasing purity of the source particle.