Quantum optical simulation of entangled particles near open time-like curves

Fabrizio Piacentini

INRIM, strada delle Cacce 91, Turin 10135, Italy

Quantum optical systems present several interesting properties, thus becoming a precious tool for simulating physical phenomena otherwise subject of theoretical speculation only, as Bose-Einstein condensation for Hawking radiation [1] or Page-Wootters model [2-6]. Closed Time-like Curves (CTCs), one of the most striking predictions of general relativity, may give rise to paradoxes (e.g. the grandfather's paradox) that can anyway be solved in a quantum network model [7], where a qubit travelling back in time interacts with its past copy. However, the price to pay for the resolution of the causality paradoxes is the breaking of quantum theory's linearity, leading to quantum cloning, uncertainty principle violation and other issues. Interestingly, violations of linearity occur even in open time-like curves (OTCs), when the qubit is initially entangled with another, chronology-respecting, qubit. In this case, non-linearity is needed to avoid entanglement monogamy violations. To preserve linearity and avoid all other drastic consequences, we discuss how the state of the qubit in the OTC is not described by a density operator, but by a pseudo-density operator (PDO) - a recently proposed generalization of density operators, unifying the description of temporal and spatial quantum correlations. Here we present the results obtained with an OTC experimental simulation exploiting polarization-entangled photons [8], providing the first full quantum tomography of the PDO describing the OTC and verifying the violation of the monogamy of entanglement induced by the chronology-violating qubit. At the same time, we show that linearity is preserved, since the PDO already contains both the spatial degrees of freedom and the linear temporal quantum evolution.

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