Entanglement-preserving single-pair measurement of the Bell parameter

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In 1965, J. S. Bell [1] turned a philosophical debate into a physical experiment capable of extracting the true nature of correlations in physical systems, opening several research fields spanning from quantum mechanics foundations to quantum technologies [2]. Over the past decades, the scientific community has thoroughly investigated Bell inequalities, eventually achieving loophole-free tests [3-5]. Nevertheless, some issues still persist: e.g., within the traditional (projective) quantum measurement framework, the wavefunction collapse and Heisenberg uncertainty principle forbid performing, on the same quantum system, all the measurements needed for evaluating the entire Bell parameter.

Conversely, here we present a method for estimating the entire Bell parameter from each entangled pair while preserving entanglement [6], ensuring its further availability. This method relies on weak measurements [7], where a tiny coupling between the observed system and the measurement device allows estimating the observables of interest while preventing the state from collapsing: one can therefore measure multiple observables on the same quantum state, extracting all the correlations needed to evaluate the full Bell parameter from each pair (although with a large uncertainty, typical of weak measurements).Our experiment provides new insights into understanding quantum mechanics foundations, like the concept of counterfactual definiteness [8]. Moreover, after the entanglement is certified, it results almost unaltered and therefore exploitable for other quantum information protocols or quantum foundations investigations, like testing novel bounds intertwining local and nonlocal correlations.

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