Extracting (anomalous) weak values by detecting a single photon

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Is it possible, when measuring a spin component of a spin-1/2 particle, to obtain a value of 100? In 1988 Aharonov, Albert and Vaidman argued that, upon pre- and postselection of particular spin states, weakening the coupling between quantum system and measuring device could allow obtaining this paradoxical result, called "weak value". Weak values have been realised in several experiments, but they are still a lively-debated topic, especially in regard of their "quantumness" and "anomalous" nature (i.e., the possibility to exceed the eigenvalue spectrum). We address these questions by presenting the measurement procedure able to obtain anomalous weak values with just a single photon detection, with no need for statistical averaging [1]. Following this line, we also show what happens if, within the same experimental procedure, we explore different directions, e.g., by making pre- and post-selection coincide (obtaining the so-called Protective Measurement, able to determine the quantum expectation value of an observable with a single detection event [2,3]) and by relaxing the constraint on the coupling weakness. Beyond clarifying the weak value meaning, demonstrating its non-statistical, single-particle nature, these results represent not only a real breakthrough in understanding quantum measurement foundations, but also a groundbreaking tool for quantum technologies, showing unprecedented measurement capability and paving the way to a widespread application of weak values in this field.

[1] E. Rebufello et al., "Anomalous weak values via a single photon detection", Light: Sci. & Appl. 10, 1026 (2021)

[2] F. Piacentini et al., "Determining the quantum expectation value by measuring a single photon", Nature Phys. 13, 1191 (2017)

[3] E. Rebufello et al., "Protective Measurement—A New Quantum Measurement Paradigm: Detailed Description of the First Realization", Appl. Sci. 11, 4260 (2021)