Anomalous weak values via a single photon detection

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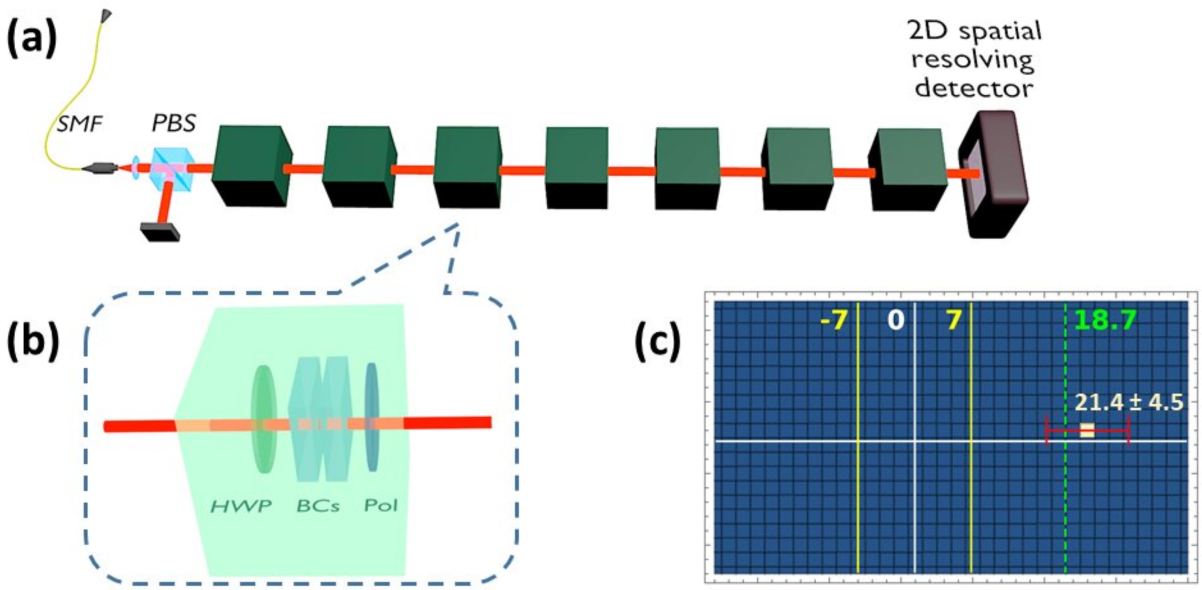

a, Experimental setup. Photons at 702 nm from a single-mode fiber (SMF) are decoupled and collimated in a free-space Gaussian mode. The Robust Weak Measurement is obtained by means of the n = 7 identical blocks put after the initial polarizing beam splitter (PBS). A 2D spatial resolving detector (an EM-CCD camera working in photon counting regime) determines the final position of the photons. b, Schematic of each of the n = 7 blocks realizing the RWM: a half-wave plate (HWP) is responsible for the preselection, a pair of birefringent crystals (BCs) implements the weak coupling between the polarization (measured observable) and the transverse momentum (measuring device) of the photon, and finally a polarizing plate (Pol) realizes the postselection. c, Measurement of an anomalous weak value with a single click. The yellow solid lines indicate the boundaries of the eigenvalues spectrum of the measured observable (i.e. the polarization of the photon at n = 7 times). Upon suitable pre- and postselection, the theoretically expected value (18.7) is highlighted by a green dashed line, while the white pixel and red uncertainty bars show the single-shot experimental result, 21.4 ± 4.5. Credit: Enrico Rebufello, Fabrizio Piacentini, Alessio Avella, Muriel A. de Souza, Marco Gramegna, Jan Dziewior, Eliahu Cohen, Lev Vaidman, Ivo Pietro Degiovanni, and Marco Genovese

In the field of quantum measurement, weak values, introduced in 1988 by Aharonov, Albert and Vaidman (AAV), represent a most intriguing and puzzling paradigm, with many properties in sharp contrast to traditional (projective) quantum measurements.

By weakening the coupling between measured particle and measuring device, and exploiting suitable pre- and postselection, AAV demonstrated that it was possible to obtain a value of 100 while (weakly) measuring the spin of a ½-spin particle.

Such a result was obtained after averaging on multiple measurements on identically pre- and postselected particles; hence, a debate started on the single-particle/statistical nature of weak values as well as on their 'quantumness', within the more general discussion on weak values as a tool for understanding the very foundations of quantum mechanics.

In a new paper published in *Light Science & Application*, a team of researchers led by Dr. Marco Genovese from the Italian metrological institute INRIM (Turin, Italy), in collaboration with people from the Brazilian metrological institute INMETRO (Rio de Janeiro, Brazil), the Max-Planck-Institut für Quantenoptik (Garching, Germany), the Bar-Ilan University (Ramat Gan, Israel), and the Tel-Aviv University (Tel-Aviv, Israel), sheds new light on this decades-old debate, with a quantum optics experiment measuring, for the first time, an anomalous weak value with a single detection event, without any statistics.

This was obtained by realizing a novel measurement paradigm dubbed Robust Weak Measurement, implemented as an iterative protocol in which the measured particle (a photon, in our case) goes through a sequence of n blocks, each implementing the preselection, weak coupling and postselection mechanisms.

In this way, the measured observable is "the sum of polarization variables of the same photon at n different times, with the spatial degree of freedom of this single photon playing the role of the measuring device."

"The experimental setup is composed of a set of n = 7 blocks in which a birefringent crystal pair realizes the weak interaction, preceded by a half-wave plate and followed by a polarizing plate. While the polarizing plate performs the postselection, the half-wave plate rotates the polarization of the photon outgoing the previous block to set the preselection state. The EM-CCD placed at the end of the n = 7 blocks detects the arrival position of the photon."

"We measured an observable with eigenvalues in the range [-7,7]. The weak value of the observable of the pre- and postselected system on which a single-click measurement was performed was 18.7, and our single click yielded 21.4 ± 4.5."

"Our findings stress the non-statistical, single-particle nature of weak values, demonstrating how a single-click measurement can provide a weak value estimate even for anomalous weak values. Furthermore, this experiment suggests a viable possibility for amplification methods effectively reducing the uncertainty contribution associated with the measurement of the pointer. This paves the way for future practical applications of the robust weak measurement paradigm."

More information: Enrico Rebufello et al, Anomalous weak values via a single photon detection, *Light: Science & Applications* (2021). DOI: 10.1038/s41377-021-00539-0

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