Observing the Trajectories of a Single Photon Using Weak Measurement

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We used weak measurement with post-selection to simultaneously gain information about the average momentum and position of single photons from a quantum dot. We were thus able to reconstruct the photon's trajectories.

Keywords - quantum measurement; weak values; trajectories; interpretations of quantum mechanics; double-slit interferometer; quantum dot

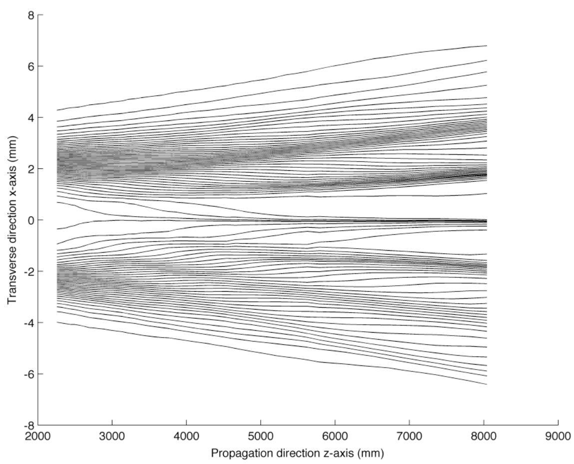
I. MEASURING TRAJECTORIES OF A SINGLE PHOTON

When the concept of *weak measurement* [1] was introduced in 1988, it represented a significant development in measurement theory, and it has since had notable success in exploring various aspects of the controversy surrounding measurement. Building on this, H. M. Wiseman argued [2] that the most natural definition for the velocity of a quantum particle at a precise position is an operational definition, in terms of *weak values*. Due to Heisenberg's uncertainty principle, we cannot determine the velocity of a particle at a precisely known position; by weakly coupling the measurement apparatus to the system, however, we can measure the mean velocity as a weak value, with only a small disturbance to the system's state vector. Wiseman's proposed definition is termed the "naïvely observable velocity", and it is consistent with the usual form given for the probability current in standard quantum mechanics.

Using a quantum dot as our single photon source, we present the first experimentally observed trajectories of a photon in a double-slit interferometer. These trajectories, originating from two separate slits, reconstruct the far-field intensity pattern due to interference. This result is interesting in light of the fact that the established picture of the evolution of quantum systems is a fundamentally probabilistic one, meaning the trajectory of a quantum particle is a somewhat ambiguous concept in the standard interpretation.

The weak measurement was a *k*-dependent polarization rotation by a thin birefringent crystal, thus encoding the momentum information in the polarization state of the photon. A quarter waveplate and beam displacer converted the polarization state into an intensity modulation varying spatially across the interference pattern. Using a system of lenses, the original slit function could be imaged at any plane from the near- to far-field. A final projective measurement of the photon's position was performed with a cooled CCD camera. By measuring the photon's average momentum and position in an imaging plane, and repeating the measurements in a series of planes, the photon's trajectories could be reconstructed over the desired range.

Trajectories of a Single Photon



The trajectories were reconstructed using data from 48 imaging planes, over a range of approximately 2 to 8 meters. These results are the first observation of trajectories in a two-slit interferometer that display the qualitative features predicted in the de Broglie-Bohm interpretation [3,4]. This work thus forms an experimental basis for the ongoing investigation of fundamental concepts in quantum theory.

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