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# What dynamics can be expected for mixed states in two-slit experiments?

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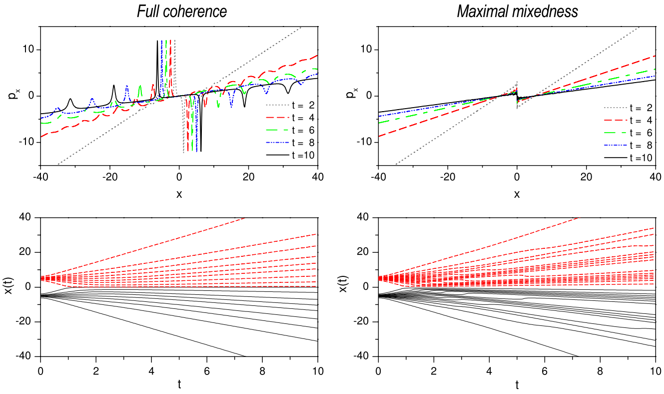
## GRAPHICAL ABSTRACT



***Top panels:*** predicted outcome from weak measurments of the transversal component of the momentum operator. ***Bottom panels:*** inferred Bohmian trajectories (average particle paths).

## HIGHLIGHTS

- The dynamics associated with mixture states in investigated by means of two simple Young's two-slit models.
- The models are prepared to be easily implemented and tested in the laboratory by means of weak measurements.
- Bohmian mechanics has been generalized to encompass statistical mixtures.
- Even for conditions of maximal mixedness numerical simulations show that the dynamics is strongly influenced by both slits.
- Accordingly, weak measurements are unable to discriminate how mixedness arises in an experiment.

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ABSTRACT

Weak-measurement-based experiments (Kocsis et al., 2011) have shown that, at least for pure states, the average evolution of independent photons in Young's two-slit experiment is in compliance with the trajectories prescribed by the Bohmian formulation of quantum mechanics. But, what happens if the same experiment is repeated assuming that the wave function associated with each particle is different, i.e., in the case of mixed (incoherent) states? This question is investigated here by means of two alternative numerical simulations of Young's experiment, purposely devised to be easily implemented and tested in the laboratory. Contrary to what could be expected a priori, it is found that even for conditions of maximal mixedness or incoherence (total lack of interference fringes), experimental data will render a puzzling and challenging outcome: the average particle trajectories will still display features analogous to those for pure states, i.e., independently of how mixedness arises, the associated dynamics is influenced by both slits at the same time. Physically this simply means that weak measurements are not able to discriminate how mixedness arises in the experiment, since they only provide information about the averaged system dynamics.

## 1. Introduction

Since the inception of quantum mechanics, our understanding of quantum systems is essentially based on two intertwined principles: uncertainty and complementarity. This landscape started changing in 2011, with experiments showing that it is possible to reconstruct the photon wave function from direct measurements [1] and to infer how photons travel (on average) in Young's experiment [2]. This apparent breach in the above principles is possible through the experimental implementation of the concept of weak measurement [3–5], which does not constitute a true violation of the quantum rules, but only looking at them with different eyes. Strong (von Neumann) measurements lead the measured system to irreversibly collapse onto one of the pointer states of the measuring device. On the contrary, weak measurements only produce a slight perturbation on the system, which may still continue as an almost unaltered evolution. Consequently, the pointer of the measuring device only undergoes a slight deviation. This information, together with the one arising from a subsequent strong measurement, is enough to completely specify the state of the system. That is, the system quantum state can be determined from a single experiment just by measuring the probability density and its transversal flow (accounted for by the current density), unlike other traditional methods, such as quantum state tomography [6–9], which require several complementary experiments in order to obtain a full picture of the corresponding quantum state. Rigorously speaking, if $|\phi_i\rangle$ and $|\phi_f\rangle$ denote pre- and post-selected states of the system, respectively, the weak value rendered by a weak measurement associated with an operator $\hat{A}$ is defined as

$$A_w \equiv \frac{\langle\phi_f|\hat{A}|\phi_i\rangle}{\langle\phi_f|\phi_i\rangle}. \tag{1}$$

Given the dependence of the weak value $A_w$ on the system pre- and post-selected states, it can be cleverly enhanced by choosing these states in such a way that they approach the orthogonality.

One of the targets of the weak-measurement technique has been the Bohmian formulation of quantum mechanics [10–16], also known as Bohmian mechanics, due to the impossible but appealing