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Extreme beam attenuation in double-slit experiments: Quantum and subquantum scenarios

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HIGHLIGHTS

- Combining high and low probability densities of intensity hybrids in double-slit setups.
- Connecting to beam attenuation techniques in neutron interferometry.
- Our "superclassical" model predicts the same results as standard quantum theory.
- Showing previously unexpected new effects in intensity hybrids for low transmissivity.
- Our explanation is based on the nonlinearity of the probability density currents.

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ABSTRACT

Combining high and low probability densities in *intensity hybrids*, we study some of their properties in double-slit setups. In particular, we connect to earlier results on beam attenuation techniques in neutron interferometry and study the effects of very small transmission factors, or very low counting rates, respectively, at one of the two slits. We use a "superclassical" modeling procedure which we have previously shown to produce predictions identical with those of standard quantum theory. Although in accordance with the latter, we show that there are previously unexpected new effects in intensity hybrids for transmission factors below $a \lesssim 10^{-4}$, which can eventually be observed with the aid of weak measurement techniques. We denote these as *quantum sweeper* effects, which are characterized by the bunching together of low counting rate particles within very narrow spatial domains. We give an

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explanation of this phenomenology by the circumstance that in reaching down to ever weaker channel intensities, the nonlinear nature of the probability density currents becomes ever more important, a fact which is generally not considered – although implicitly present – in standard quantum mechanics.

1. Introduction

Continuing the search for new, and perhaps surprising, features of quantum systems, one option is to steadily decrease the intensity of a channel in one spatially constrained area, as compared to a reference intensity in another, equally constrained area. For example, one can employ the usual double-slit experiments and modify one of the two slits' channels such that the corresponding outgoing probability density is very low compared to that of the other slit. We call a combination of such distributions of high and low probability densities, or intensities, respectively, *intensity hybrids*.

Since the 1980s, one possibility to experimentally establish and probe such hybrids has been through the introduction of beam attenuation techniques, as demonstrated in the well-known papers by Rauch's group in neutron interferometry [1,2]. In the present paper, we re-visit these experiments and results from a new perspective, and we also discuss new, previously unexpected effects. For, our group has in recent years introduced a "superclassical" approach to describe and explain quantum behavior as an emergent phenomenon in between classical boundary conditions on the one hand, and an assumed classical subquantum domain at vastly smaller spatial scales on the other [3–11]. Here we are going to apply our approach to the above-mentioned intensity hybrids. Our main result is that in employing ever weaker channel intensities, nonlinear effects become ever more important, which are generally not considered – although implicitly present – in ordinary quantum mechanics, but which are a crucial characteristic of subquantum models as the one developed by our group. Whereas the intensity distributions are predicted to be the same for the standard quantum mechanical and our superclassical approach, respectively, more detailed information is available when the behavior of average trajectories is studied. It is the latter which exhibits said nonlinear behavior which we term *quantum sweeper effects*. For these effects, experimental tests are feasible with the aid of weak measurement techniques.

2. Deterministic and stochastic beam attenuation in the double slit and their superclassical modeling

2.1. Beam attenuation in neutron interferometry

Deterministic and stochastic beam attenuation have been studied extensively in neutron interferometry, beginning with the work by Rauch and Summhammer in 1984 [1]. More recently, an interesting model of these results has been presented by De Raedt et al. [12] with the aid of event-by-event simulations, thus confirming the possibility to describe the known results even without the use of quantum mechanics. Our approach, in contrast, though also not relying on the quantum mechanical formalism, nevertheless is an attempt at a "deeper level" modeling from which the quantum mechanical results are expected to emerge. In other words, as our model is intended ultimately to go beyond standard quantum mechanics, but also to provide the quantum results as a limiting case, we shall first use the physics of beam attenuation as a means to verify the agreement with the quantum mechanical predictions. In a second step, then, we shall exploit the "extremes" of the quantum as well as of our superclassical descriptions, respectively, i.e. consider parameter values that cover a vast range of orders of magnitude so as to study extreme examples of intensity hybrids as introduced in Section 1. We shall then find results that look rather surprising from the viewpoint of standard quantum mechanics, but are fully understandable with our model.