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# Event-by-Event Simulation of the Hanbury Brown-Twiss Experiment with Coherent Light

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**Abstract.** We present a computer simulation model for the Hanbury Brown-Twiss experiment that is entirely particle-based and reproduces the results of wave theory. The model is solely based on experimental facts, satisfies Einstein's criterion of local causality and does not require knowledge of the solution of a wave equation. The simulation model is fully consistent with earlier work and provides another demonstration that it is possible to give a particle-only description of wave phenomena, rendering the concept of wave-particle duality superfluous.

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## 1 Introduction

Computer simulation is widely regarded as complementary to theory and experiment [1]. Usually, the fundamental theories of physics provide the framework to formulate a mathematical model of the observed phenomenon, often in terms of differential equations. Solving these equations analytically is a task that is often prohibitive but usually it is possible to study the model by computer simulation. Experience has shown that computer simulation is a very powerful approach to study a wide variety of physical phenomena. However, recent advances in nanotechnology are paving the way to prepare, manipulate, couple and measure single microscopic systems and the interpretation of the results of such experiments requires a theory that allows us to construct processes that describe the individual events that are being observed. Such a theory does not yet exist.

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Indeed, although quantum theory (QT) provides a recipe to compute the frequencies for observing events, it does not describe individual events, such as the arrival of a single electron at a particular position on the detection screen [2–5]. Thus, we face the situation that we cannot rely on an established physical theory to build a simulation model for the individual processes that we observe in real experiments. Of course, we could simply use pseudo-random numbers to generate events according to the probability distribution that is obtained by solving the Schrödinger equation. However, that is not what the statement "QT does not describe individual events" means. What it means is that QT tells us nothing about the underlying processes that give rise to the frequencies of events observed after many of these events have been recorded. Therefore, in order to gain a deeper understanding in the processes that cause the observed event-based phenomena, it is necessary to model these processes on the level of individual events without using QT. The challenge therefore is to find algorithms that simulate, event-by-event, the experimental observations that, for instance, interference patterns appear only after a large number of individual events have been recorded by the detector [4,6], without first solving the Schrödinger equation.

In this paper, we leave the conventional line-of-thought, postulating that it is fundamentally impossible to give a logically consistent description of the experimental results in terms of causal processes of individual events. In other words, we reject the dogma that there is no explanation that goes beyond the quantum theoretical description in terms of averages over many events and search for an explanation of the experimental facts in terms of elementary, particle-like processes. It is not uncommon to find in the recent literature, statements that it is impossible to simulate quantum phenomena by classical processes. Such statements are thought to be a direct consequence of Bell's theorem [7] but are in conflict with other work that has pointed out the irrelevance of Bell's theorem [8–31]. This conclusion is supported by several explicit examples that prove that it is possible to construct algorithms that satisfy Einstein's criterion for locality and causality, yet reproduce *exactly* the two-particle correlations of a quantum system in the singlet state, without invoking any concept of QT [32–37]. It is therefore an established fact that purely classical processes can produce the correlations that are characteristic for a quantum system in an entangled state, proving that from the viewpoint of simulating quantum phenomena on a digital computer, Bell's no-go theorem is of no relevance whatsoever.

The present paper builds on earlier work [32–45] that demonstrates that quantum phenomena can be simulated on the level of individual events without first solving a wave equation or invoking concepts of QT, wave theory or probability theory. Specifically, we have demonstrated that it is possible to construct event-by-event processes, that reproduce the results of QT for single-photon beam-splitter and Mach-Zehnder interferometer experiments [6], Einstein-Podolsky-Rosen-Bohm experiments with photons [46–48], Wheeler's delayed-choice experiment with single photons [49], quantum eraser experiments with photons [50], double-slit and two-beam single-photon interference, quantum cryptography protocols, and universal quantum computation [40,41]. Ac-