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Comment on "Experimental Test of an Event-Based Corpuscular Model Modification as an Alternative to Quantum Mechanics"

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We scrutinize the experiment[1)] that purports to falsify the results of an event-based simulation model of a Mach–Zehnder interferometer in which the relative phase may change with the passage of each photon.[2)] It is shown that an event-based simulation of the integrated optics device used in the experiment reproduces the results of the idealized version of this experiment and of quantum theory, indicating that the claim that the experimental results falsify the event-based approach, is premature.

In Ref. 2, we proposed a single-photon Mach–Zehnder interferometer (MZI) experiment (see Fig. 1) in which the variable x, which controls the phase in one arm of the interferometer, is allowed to change before the particle enters the MZI but should be fixed during the passage of the particle through the MZI. All optical components of the MZI operate independent from each other so that only the particle passing through the variable phase shifter [represented by $\phi_1(x)$ in Fig. 1] can carry the information about the value of x to the second beam splitter. It was shown that there exist certain conditions,[2)] for which the event-based corpuscular model (EBCM) for the MZI depicted in Fig. 1 yields results which are different from those predicted by quantum theory.[2)] Therefore, in principle it should be possible to perform an experiment to test these predictions. Such an experiment would lead to one of the four possible conclusions, namely

(0) the experiment can be described by quantum theory and also by the EBCM unless the independence condition is perfectly satisfied in the experiment,
(1) the experiment can be described by quantum theory, and thus not by the current EBCMs,
(2) the experiment cannot be described by quantum theory but can be described by the current EBCMs or variations thereof,

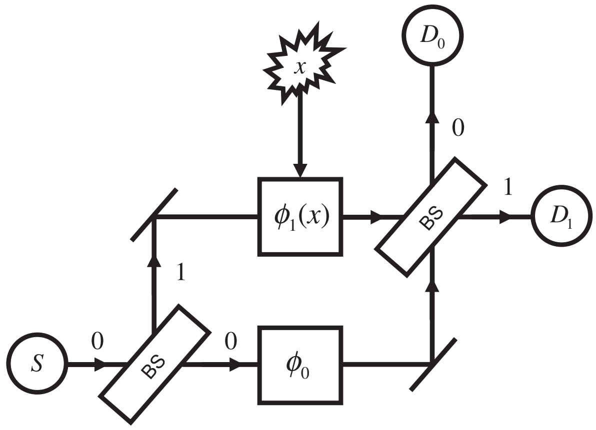

Fig. 1. Conceptual diagram of the proposed Mach–Zehnder interferometer (MZI) experiment. S: light source; BS: 50–50 beam splitter; ϕ_0: fixed phase shift; $\phi_1(x) = (\pi/2)\delta_{x,-1}$: variable phase shift controlled by the external variable $x = \pm 1$; D_0, D_1: detectors. In single photon experiments x may change before the photon enters the MZI but not during the passage of the photon through the MZI. The recorded dataset for N detection events is given by $\{x_i, d_{0,i}, d_{1,i} | i = 1, \ldots, N\}$ where $d_{k,i} = 1$ if detector D_k, $k = 0, 1$ fired and $d_{k,i} = 0$ otherwise. The value of the experimental setting parameter x is known at each moment in time.

(3) the experiment can neither be described by quantum theory nor by the current EBCMs.

A first implementation of this proposal is reported in Ref. 1. According to Ref. 1, the experimental results are compatible with conclusion (1) and falsify the EBCM of the MZI shown in Fig. 1. However, in this experiment the MZI is realized as an integrated-optics device[1)] and as there is no evidence that the condition of independent operation is realized, this conclusion is premature.

Although Ref. 1 shows a schematic of the layout of the waveguides and electrodes, of the MZI device, it does not provide any specification nor any characterization of the device actually being used, except for mentioning that it is a single-crystal lithium niobate integrated optics device.[3,4)] Non-centrosymmetric crystals such as lithium niobate exhibit electro-optic (the application of an external electric field may change the index of refraction) pyroelectric (changes in device temperature change the atomic positions, hence the electrical polarization of the material) and photoelastic (birefringence due to mechanical stress also associated with acoustic waves in the material) effects.[3)] Because of the long-range nature of the electrical and elastic forces which are responsible for these effects, one of the main premises of our proposal,[2)] the independent operation of optical components, is not satisfied. As the applied voltages might affect the crystal as a whole, this feature should be build into an EBCM of the integrated-optics device.

One simple way to incorporate this feature into an EBCM is to assume that for each set of applied voltages, the events are processed by a different set of machines. Logically speaking, this implies that for each set of values of the applied voltages, the machines that represent the beam splitters employ different internal registers, implying that the MZI is implemented as a collection of interconnected components.

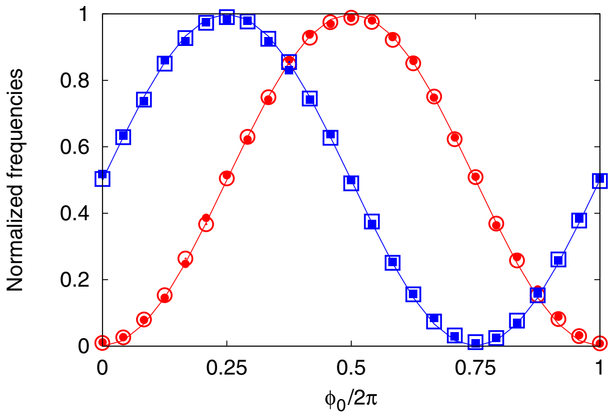

Fig. 2. (Color online) Frequencies of counts registered by detector D_0, conditioned on the variable x for fixed and random x and normalized to the total number of events N. Open circles: data conditioned on $x = +1$ fixed; solid circles: data multiplied by 2, conditioned on $x = +1$, x random with each event; open squares: data conditioned on $x = -1$ fixed; solid squares: data multiplied by 2, conditioned on $x = -1$, x random with each event. Solid lines: predictions of quantum theory. Number of events per data point $N = 10000$ and learning parameter[2] $\alpha = 0.99$.

The simulation results of such an EBCM are shown in Fig. 2. It is clear that this EBCM correctly reproduces the results of quantum theory if the phase shift associated with the variable x is fixed or changes randomly with each event. These results show that, in contrast to the claim of Ref. 1, the EBCM can reproduce the results of the idealized experiment.

In essence, what the experimental results reported in Ref. 1 demonstrate is that on the level of single events, the integrated-optics device, operating as a MZI,[5] cannot be modeled as a collection of independent components (beam splitters, phase shifters, wave guides), which from the viewpoint of device physics is hardly a surprise. Therefore, it would be of interest to perform experiments that characterize the effects of the interconnection and, more desirably, that realize the independent component setup.

There are many other quantum optics[2] and neutron interference experiments[6] which have been simulated by a collection of independent processors, all using the learning mechanism. In principle, it is possible to design experiments that probe the specific dynamics of these models. Furthermore, we also proposed EBCMs for the Einstein–Podolsky–Rosen–Bohm (EPRB) thought experiment.[7–13] which do not require (but may have) processing elements with learning capability. Data of EPRB experiments has been analyzed,[14] indicating that more precise experiments are called for.

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