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Reply to "Comment on 'Test of local causality with very short light pulses' "

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A clarification concerning the solution of the initial-value problem for the propagation of light pulses in dispersive media is given. In a proper interpretation, this solution corresponds to two single pulses traveling in opposite directions. Furthermore, a critical review of important research related to Rubin's arguments but not mentioned by him in the preceding Comment [Phys. Rev. A **41**, 1727 (1990)] is presented.

Clearly my paper did not intend to disprove Rubin's calculations,[1] nor did I prove the general conjecture that quantum field theory is consistent with the impossibility for faster-than-light communication. My major aim has been the proposal of a test of relativity theory by pulse propagation, which has become feasible by modern nonlinear optical techniques. In my paper[2] I assumed the initial value $\partial u(y,t=0)/\partial t=0$, as is often done[3] to simplify the calculation of pulse propagation in dispersive media. This specific choice of the initial value means that at times immediately before $t=0$ the wave consisted of *two* pulses, both moving towards the origin such that at $t=0$ they coalesced with $u(y,t=0)=\theta(\sigma/2-|y|)$. At later times $t>0$ one can expect these two pulses to reemerge, traveling in opposite directions. Indeed, the formal solution is given by

$$u(y,t)=\frac{1}{2}\left\{\theta\left[\frac{\sigma}{2}-|y+t|\right]+\theta\left[\frac{\sigma}{2}-|y-t|\right]\right.$$
$$+\theta\left[\left[\left[\frac{\sigma}{2}-t\right]^2-y^2\right]\right.$$
$$\left.\left.\times\left[y^2-\left[\frac{\sigma}{2}+t\right]^2\right]\right]\right\},$$

in consistency with the above initial values. One should, however, bear in mind that this solution represents *two* pulses $u_\pm(y,t)=\theta(\sigma/2-|y\pm t|)$ traveling with opposite velocities. Each one of these pulses u_+ and u_-, *taken separately, is inconsistent* with the initial value $\partial u(y,t=0)/\partial t=0$.

My attempt to give an appropriate context of the ongoing local causality debate did not mention important contributions. Since Rubin does not deal with these either, I summarize them as follows. Rubin's work is a recalculation of earlier results by Shirokov [see Shirokov's review article,[4] Chap. 2, e)–h)]. Ferretti showed that the acausal contributions for $T<L/c$ (L is the distance between two atoms emitting and reabsorbing a photon) vanish for $(1+1)$-dimensional QED.[5] Recently, Valentini proved an identical result for Rubin's model for standard $(3+1)$-dimensional QED.[6] Specific scattering amplitudes, for instance, those corresponding to the emission and reabsorption of a photon by two bare atoms in second-order perturbation theory, yield nonvanishing transition amplitudes for $T<L/c$. However, by taking into account *all* contributions to this order, in particular, from interference between the two indistinguishable ways of jointly emitting a pair of photons, these nonlocal terms cancel. To discriminate between particular nonlocal matrix elements and the complete second-order contributions, one has to measure the photon content of the initial and final states, which requires detection of photons in the space surrounding the two atoms. Thus one recognizes nonlocal events only at times $T\geq L/c$ *after* they took place, making superluminal communication impossible.[7] For a more detailed account of these considerations, see Shirokov, Ref. 4 and Valentini, Ref. 6.

[1]M. H. Rubin, Phys. Rev. D **35**, 3836 (1979).
[2]K. Svozil, Phys. Rev. A **39**, 2222 (1989).
[3]See, for instance, J. D. Jackson, *Classical Electrodynamics*, 2nd ed. (Wiley, New York, 1975), Sec. 7.9.
[4]M. I. Shirokov, Usp. Fiz. Nauk **124**, 697 (1978) [Sov. Phys.—Usp. **21**, 345 (1978)].
[5]B. Ferretti, *Old and New Problems in Elementary Particles* (Academic, New York, 1968).
[6]A. Valentini (unpublished).
[7]These nonlocal contributions in quantum-field theory to some extent resemble EPR-type measurements in quantum mechanics, where the intrinsic undecidability of single quantum events assures that the stronger-than-classical quantum correlations cannot be used for signaling.

