Could the OPERA setup send a bit of information faster than light?

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We argue that with the current experimental setup of the OPERA neutrino experiment no ‘bit’ of information faster than light was or could be sent, and therefore no violation of Lorentz symmetry and/or causality was observed.

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I. INTRODUCTION

In the recent OPERA neutrino experiment at Gran Sasso Laboratory, superluminal propagation of neutrinos was reportedly observed\cite{1}. Since then lots of explanations of this surprising result have emerged, e.g. discussions on (the inconsistencies of) tachyons\cite{2}, on (the problematic relation with) astrophysical data\cite{3}, on environmental explanation\cite{4}, on experimental details\cite{5}, on general relativity effects\cite{6}, etc. (for a full list see the papers citing\cite{1}).

We assume in this note that the experiment is correct, so there is no systematic shift in the measured data. Then one can ask whether it is possible to send a bit of information faster than the speed of light with this experimental setup, which would really mean violation of the Lorentz symmetry or, even worse, of the well known causality principle.

Apparent violation is appealing but not conclusive (see \cite{1} for a related idea). In this respect it is interesting to note that apparent superluminal phenomena exist, such as the famous EPR paradox with superluminal ‘spooky’ action at distance. However, up to now it has proved impossible to send information faster than light.

II. DISCUSSION

During the experiment an approximately step-shaped proton distribution function (PDF) was produced at CERN with time length of about 10000 ns, see Fig. 1 and also Fig. 9 of\cite{1} for the precise form. Just after the measurement of the PDF, the protons hit a target, resulting in the productions of the mesons $\pi$ and $K$, which subsequently decay into muonic neutrinos. The latter travel for about $d = 730$ km in the inner earth crust and reach the neutrino detectors of OPERA placed in Gran Sasso. One expects that the distribution of muonic neutrinos has the same (or very similar) shape of the original PDF. In this way it is possible to measure the (mean) velocity of muonic neutrinos.

The finding is that the neutrino step function arrives about 60 ns earlier than expected. Technically, one has to shift by 1048.5 ns the (scaled) PDF corresponding to the travel with the speed of light $c$. Then, one has to correct for 987.8 ns, which is the resulting time delay of various desynchronization effects. Finally, one is left with the striking result that the neutrinos arrived $60.7 \pm 13.5$ ns ‘before light’, thus travelling at a velocity $v_\nu > c$. For the following discussion it is crucial to stress that the resulting time shift of 60 ns, and therefore the conclusion that $v_\nu > c$, is the result of a statistical analysis including the leading as well as the trailing edges of the step functions. It is a collective result based on the full length of the signal of about 10000 ns.

We turn now to the main question of this note: is it possible to send a bit of information with the described OPERA experimental setup? One may ask whether waiting only for the leading edge of the signal would be enough (see the left plots of Fig. 12 of \cite{1}). The leading edge lasts about 1000 ns, which is much larger than the 60 ns time difference. Restricting to these data only, it is very hard to see any time shift. Moreover, the data oscillate and it would be impossible to agree on the exact time of the incoming of the bit. More in general, it seems impossible to send a bit of information faster than light using only a very small portion of the PDF.

In the next section we elaborate in more detail, by considering a simple modification of the PDF, on the possibility to send a bit of information.

III. A GEDANKENEXPERIMENT

Suppose we want to use the CNGS neutrino stream to transfer one bit, such that the information arrives earlier than it would have had with standard light-based communication. One would then need to shape the PDF (and the subsequent travelling neutrino packet) as exem-
plified in Fig. 2 (we assume that the proton beam can be blocked at will). Over a background without neutrinos, a bit-carrying signal is composed by two parts: part (I) triggers the receiver, warning it that the bit will be encoded in part (II). This two-part structure is necessary because the receiver does not know in advance when exactly will the information be sent.

An important observation is that, while the “button” at CERN is pressed corresponding to point a in Fig. 2, the bit will be completely received only at point b, that is, after the whole sequence has been decoded, neglecting processing times and similar practicalities. Thus the whole bit takes a somewhat large time $\Delta t$ to be transmitted.

Moreover, the duration of parts (I) and (II) have to be previously agreed upon by both sides. Denoting the time-resolution of the receiver by $\Delta \tau = 50$ ns, we can write $\Delta t = 2N\Delta \tau$, with $N$ the (smallest) number of data points necessary to identify unambiguously the onset of a signal. Looking at the error bars and slope of the curves in Fig. 12 of [1] (also sketched here in Fig. 2), we give a conservative estimate $N \geq 3$.

In order to achieve a truly faster-than-light transmission of a bit, one needs even the tail (point b) of the packet to arrive faster than a light signal, shot at moment a, hence

$$\Delta t = 2N\Delta \tau < d \left( \frac{1}{c} - \frac{1}{v_N} \right), \tag{1}$$

In the real-life case of the OPERA setup, the right-hand side is 60 ns, which makes it impossible to fulfill the above requirement.

One may argue that a simple one-pulse signal (much like part (I) of Fig. 2 alone) would already imply violation of Lorentz symmetry (or causality). This situation just amounts to dropping the factor 2 in Eq. 1, but the conclusions would remain unchanged. Moreover, it should also be noted that receiving a neutrino in the detector implies a further time delay before the data are received by the observer. This is contrary to receiving a photon, where the use of scintillators allow for an (almost) instantaneous processing: taking this into account amounts in a further increase in $N$.

Finally, it is amusing to imagine the existence of a straight tunnel connecting CERN and Gran Sasso. This tunnel would be helpful to send, starting at the same time $t = t_a$, a standard light-bit. In this way it could be possible to check which signal arrives first. Unfortunately, as (almost) everyone knows, the construction of such a tunnel is impossible for the moment (the price would surely overshoot $45 \cdot 10^6$ euros).

IV. CONCLUSION

In this work we have studied if it is possible to send a bit of information with speed larger than $c$ with the experimental setup of OPERA. Our result is negative: at present, this does not seem to be feasible.

Our arguments are based on the particular present setup and therefore one may object that, by improving the luminosity and the precision of the experiment, or putting the neutrino detectors much further away, the sending of a signal faster than $c$ would be indeed possible. However, this represents an extrapolation which is based on the assumption that nothing will change when doing that. Due to the fact that Lorentz symmetry and causality are basic principles of our understanding of nature, we believe that the rejection of (at least) one of them should be motivated by the actual transmission of a bit of information faster than $c$ and not by an extrapolation: Nature may be subtle, protecting these basic principles with the help of some not yet understood ‘censorship’ mechanism.

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