Is it possible to rescue superluminal neutrinos?*

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Abstract

A trick to construct dispersion relations that provide the superluminal neutrinos as suggested by OPERA, without spontaneous emission of pairs and relevant anomalies in the pion decay,is described.

The recent measurements of the neutrino velocity [1] have created a lot of excitement and a flurry of theoretical proposals to explain their meaning [2]. But it is still unclear how to have superluminal neutrinos, without severely affecting the pion decay process through which they are produced [3, 4, 5, 6, 7] or without implying that high energy neutrinos will spontaneously decay by pair emission [8, 4, 9]. Indeed, it has been claimed that ***all*** the dispersion laws proposed so far lead to inconsistencies, see, e.g., [7]. Thus, the question arises: is it possible to find some dependence of the neutrino energy E upon the neutrino 3-momentum $p \equiv |\vec{p}|$ that does not contradict any experimental fact, including OPERA findings? In the following, we explicitly construct a specific example of such a dispersion law.

The main point is just to suppose that, in a certain range of momenta–say, between 1 GeV and 100 GeV–the velocity of the neutrinos, regarded as a function of the momentum p, equals the velocity of the light on average, but that ***usually*** exceeds the velocity of the light. A specific realization of this hypothesis is as follows. Assume that the group velocity of the neutrino is

$$v(p) = \frac{dE}{dp} = \begin{cases} 0 & \text{if } p_n - \delta < p \leq p_n \\ 1/(1-\delta/\Delta) & \text{if } p_n < p \leq p_n + \Delta \end{cases}$$

where p_n with $n = 1, 2, 3...$ is a set of equally spaced momenta, with $p_{n+1} - p_n = \Delta + \delta$ (we use $\hbar = c = 1$). We are interested in the case $0 < \delta \ll \Delta$, thus the spacing coincides with Δ in good approximation. The neutrino wave packet is small, about $1/L = 2 \times 10^{-10}$ eV (L =length of the pion decay tunnel). If Δ is much larger than $1/L$, most of the neutrinos have $v \simeq 1 + \delta/\Delta$. In order to account for the finding of OPERA we have $\delta/\Delta \sim 2.5 \times 10^{-5}$; only 1 neutrino in 40,000 is so slow, that is missed by the detector.

The function $E(p)$ is given by $\int v(p)dp$. By a suitable constant of integration, it can be arranged to resemble the graph of Fig. 1. Evidently, $E(p)$ is always close to the standard value $E = p$: the maximum deviation is $|E(p) - p| \leq \delta/2$ (neutrino mass effects are neglected). Also the "effective neutrino mass", defined as $m^2(p) \equiv E(p)^2 - p^2$ [8], is small: at leading order in δ, we have $|m^2(p)| \leq p\ \delta$. If we require that this is less than the threshold for pair production, $4m_e^2$, where m_e is the electron mass, we get another condition $\Delta < m_e \times 80$ GeV$/p$ that can be comfortably satisfied: this implies that the process of pair production can be inhibited. Moreover, from the formulae of [7], it is quite evident that the alteration of the decay rate of the pion is very small, and that it decreases with Δ.

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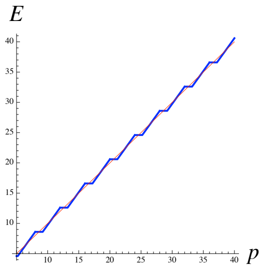

Figure 1: *A neutrino dispersion law (depicted in blue) which implies the existence of superluminal neutrinos, but that remains always close to the ordinary dispersion law* $E = p$ *(shown in red). For the purpose of illustration, the features required for a successful interpretation of OPERA measurements, discussed in the text, have been greatly exaggerated in the picture. The energy and the momentum are in GeV.*

Therefore, it seems that superluminal neutrinos, which could explain the measurements of OPERA, do not necessarily imply contradictions with the above mentioned processes. The dispersion relation that we described above is non-decreasing, $E(p) \leq E(p')$ when $p \leq p'$ and can be easily rendered continuous in the whole range of momenta. In principle, one can generalize this to the case of unequal momentum spacing; to account for some dependence of the neutrino velocity on the momentum; or to relax a bit the assumption the some of the neutrinos are very slow.

But from the point of view of physics, this is not enough. Such a dispersion relation stands in striking contrast with the much simpler law $E = p$ that follows from special relativity; a theory rooted into the Maxwell equations, that describes the nature of the space-time, and moreover, that is well tested and enormously successful. The previous hypothesis, instead, did not stem from any physical principle, but only from the desire that no experimental fact should be contradicted, which is a much weaker position. It is unclear whether such a dispersion law can be ruled out, if not by further measurements of the neutrino velocity. The famous words *subtle is the Lord but malicious is not* [10] come immediately to the mind, and a natural reaction of a physicist would be to reject this possibility without further ado. However, hoping it could inspire some of us to find a more convincing explanation and in order to proceed further in the discussion, I decided to outline such an extreme possibility as directly as possible, for the occasion of the meeting on the superluminal neutrinos in Paris.

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