A Complete Relativity Theory Predicts with Precision the Neutrino Velocities Reported by OPERA, MINOS, and ICARUS

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The present paper utilizes the recently proposed Complete Relativity Theory (CR) for the prediction of neutrino velocity in a prototypical neutrino velocity experiment. The derived expression for the relative difference of the neutrino velocity with respect to the velocity of light is a function of the anticipation time δt, the traveled distance D and the light velocity c, measured on Earth. It is independent neither on the traveling particle type nor on its energy level. With regard to fast neutrinos it is shown that the derived equation predicts with precision the results reported by OPERA, MINOS, and ICARUS. Since CR postulates that all physical entities, including the velocity of light, are relativistic entities, it follows that even though the results of the aforementioned experiments fail to support the neutrino superluminality claim, their precise prediction based on a theory that diametrically opposes SR, provides strong evidence for the inadequacy of SR in accounting for the dynamics of quasi-luminal particles. The aforementioned notwithstanding, a direct calculation of SR's predictions for the above mentioned studies yields grossly incorrect results.

1 Introduction

The findings of several high energy experiments conducted by MINOS, OPERA, ICARUS and other collaborations suggest that neutrinos travel at super-luminal or quasi-luminal velocities, e.g. [1–6]. The possibility of quasi-luminal neutrinos has been also confirmed by cosmological observations, see, e.g. [7, 8]. Among all experimental findings, the one that attracted most interest was the result reported in 2011 by OPERA [1], which (ostensibly) indicated that neutrinos have travelled faster than light. The reported anticipation time was $\delta t = 60.7 \pm 6.9\,(\text{stat.}) \pm 7.4\,(\text{sys.})$ ns and the relative neutrino velocity was $\frac{v_n - c}{c} = (5.1 \pm 2.9) \times 10^{-5}$. Many physicists have described the possibility that OPERA may have broken the limit of light-velocity as one of the greatest discoveries in particle physics, provided that it is replicated by an independent group, and CERN's Research Director announced in a press conference that "If this measurement is confirmed, it might change our view of physics" [9].

Within few months, numerous papers were written, proposing that OPERA's experimental design and/or measurements were flowed, or suggesting various explanations that accord with standard theories, see, e.g. [10–20]. Soon after, the ICARUS collaboration reported a null result, which contradicted OPERA's superluminal one [3]. The anticipation time measured by ICARUS was $0.3 \pm 4.0\,(\text{stat}) \pm 9.0$ (sys.) ns, which is one order of magnitude lower than the result reported by OPERA [1]. The following events witnessed the discovery of hardware malfunctions which resulted in measurement error and the publication of a corrected null result [5].

Theoretically, the possibility of superluminal particles has been treated within the framework of General Relativity by A. Zelmanov's theory of "physically observable quantities" [21, 22]. Other models which entertain the possibility to construct theories in which neutrinos travel faster than photons have recently been proposed, e.g. [20, 23].

Although many questions pertaining to the neutrino superluminality issue remain open to theoretical inquiry, the general stance among physicists contends that for the time being both superluminality and subluminality of neutrinos cannot be dismissed by existing data, and that more investigation of this issue is needed [23, 24]. The common view, which I shall refute hereafter, contends that the null result based on data aggregation from existing experiments, is consistent with Special Relativity and with the limits put on Lorentz violations, e.g. [12, 15, 24, 25].

Here I shall show that for three experiments conducted by MINUS, OPERA, and ICARUS, Special Relativity (SR) yields *grossly incorrect results* and that an expression for $\frac{v_n - c}{c}$ derived on basis of Complete Relativity Theory (CR), detailed in [26] in this volume, yields *precise predictions* for the three aforementioned experiments.

The reminder of the paper is organized as follows: Section 2 details a derivation of $\frac{v_n - c}{c}$ based on SR, and demonstrates that it yields grossly incorrect predictions for all the discussed experiments. Section 3 provides a brief description of CR, and utilizes the one-way time transformation for deriving an expression for $\frac{v_n - c}{c}$ in a typical quasi-luminal neutrino experiment. The derived expression is then used to make precise predictions for the results reported by the above mentioned studies. Section 4 ends with concluding remarks.

2 Special Relativity predictions

In general, all neutrino-velocity experiments utilized the same technology. Thus, for the sake of convenience and without loss of generality, I analyze the one implemented by OPERA shown schematically in Fig. 1.

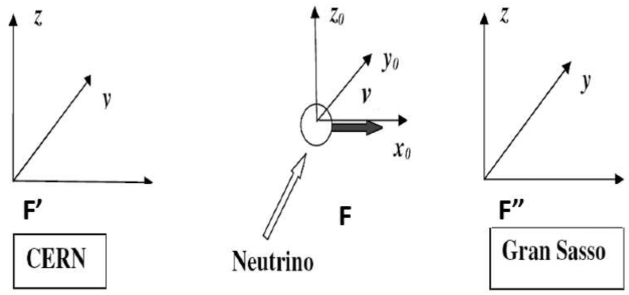

Fig. 1: The OPERA Setup.

From the perspective of Special Relativity (SR), the start and end laboratories F' and F'' are stationed in one frame of reference. The time dilation predicted by SR is given by:

$$\Delta_{SR} = T''_{G.Sasso} - T'_{CERN} = \frac{1}{\sqrt{1-\left(\frac{v_n}{c}\right)^2}}\, T. \tag{1}$$

Where Δ_{SR} is the time difference between the start and end points, v_n is the neutrino's velocity, c is the velocity of light as it is measured on earth ($c = 299792.458$ km/sec) and T is the rest time at the neutrino's frame of reference F given by:

$$T = \frac{D}{v_n}. \tag{2}$$

Where D is the distance between the source of the neutrino beam and the end point detector. Substituting the value of T in Eq. 1 we obtain:

$$\Delta_{SR} = \frac{1}{\sqrt{1-\left(\frac{v_n}{c}\right)^2}}\,\frac{D}{v_n}. \tag{3}$$

For an early neutrino arrival time (δt) with respect to light photons we get:

$$\Delta_{SR} = \frac{D}{c} - \delta t. \tag{4}$$

Substituting the value of Δ_{SR} from Eq. (3) in Eq. (4) and solving for $\frac{v_n}{c}$ we obtain:

$$\frac{v_n}{c} = \pm\sqrt{\frac{1}{2}\left(1+\sqrt{1-\frac{4}{1-\left(\frac{c\delta t}{D}\right)^2}}\right)}. \tag{5}$$

For the result reported by ICARUS 2011: $\delta t = (0.3 \pm \pm 4.0\,(\text{stat}) \pm 9.0\,(\text{sys.})$ and $D = 674.385$ km. Substituting in Eq. 4 we get:

$$\frac{v_n}{c} \approx \pm(0.86603 + 0.5i) \tag{6}$$

And,

$$\frac{c - v_n}{c} = \pm(-0.13397 + 0.5i). \tag{7}$$

Calculations of SR's prediction of $\frac{c-v_n}{c}$ for the results reported by MINOS and OPERA (not reported here) yield similar (incorrect) results.

3 Complete Relativity predictions

Complete Relativity Theory (CR) rests on two postulates:

1. The magnitudes of all physical entities, as measured by an observer, depend on the relative motion of the observer with respect to the rest frame of the measured entities.
2. All translations of information from one frame of reference to another are carried by light or electromagnetic waves of equal velocity.

It should be stressed that the first postulate applies to all measured entities, *including the velocity of light*. CR treats the velocity of light as a relativistic quantity and not as an invariant one as postulated by SR. The derivations of CR's time, distance, mass-density and energy transformations are detailed elsewhere in this volume [26].

The derivation of a theoretical expression for $\frac{v_n - c}{c}$ in a typical superluminal neutrino experiment requires only the one-way time transformation. Viewed in the framework of CR, the experimental setup depicted in Fig. 1 includes *three* frames of reference: F' at CERN, F'' at Gran Sasso and F, the neutrino rest frame. F is *departing* from F' with velocity v_n and *approaching* F'' with velocity $-v_n$. F' and F'' are at rest relative to each other. According to CR [26], the time transformation for the one-way travel is given by:

$$\frac{t}{t_0} = \frac{1}{1-\frac{v}{c}} \tag{8}$$

Thus, we can write:

$$T'_{CERN} = \frac{1}{1-\frac{v_n}{c}}\, T. \tag{9}$$

Where v_n is the velocity of the neutrino relative to CERN's frame of reference F'.

Since the neutrino travelled *towards* Gran Sasso, applying the time transformation to F'' yields:

$$T''_{G.Sasso} = \frac{1}{1-\left(\frac{-v_n}{c}\right)}\, T = \frac{1}{1+\frac{v_n}{c}}\, T. \tag{10}$$

Experiment	Neutrino Anticipation Time (δt)	Experimental $\frac{v_n - c}{c}$	Theoretical $\frac{v_n - c}{c}$
MINOS $D = 734298.6$ m	$\left(126 \pm 32\,(\text{stat.}) \pm 6\,(\text{sys.})\right)$ ns	$(5.1 \pm 2.9)\,(\text{stat}) \times 10^{-5}$	$\mathbf{5.14 \times 10^{-5}}$
OPERA 2012 (corrected result) $D = 730085$ m	$\left(6.5 \pm 7.4\,(\text{stat.}) \begin{array}{c}+9.2\\-6.8\end{array}\,(\text{sys.})\right)$ ns	$\left(2.7 \pm 3.1\,(\text{stat.}) \begin{array}{c}+3.8\\-2.8\end{array}\,(\text{sys.})\right) \times 10^{-6}$	$\mathbf{2.67 \times 10^{-6}}$
ICARUS 2012 $D = 730478.56$ m	$\left(0.10 \pm 0.67\,(\text{stat.}) \pm 2.39\,(\text{sys.})\right)$ ns	$\left(0.4 \pm 2.8\,(\text{stat.}) \pm 9.8\,(\text{sys.})\right) \times 10^{-7}$	$\mathbf{0.41 \times 10^{-7}}$

Table 1: Experimental results and theoretical predictions for three superluminal neutrino experiments.

The time difference between CERN and Gran Sasso's could be written as:

$$D_t = T''_{G.Sasso} - T'_{CERN} =$$

$$= \left[\frac{1}{1+\frac{v_n}{c}} - \frac{1}{1-\frac{v_n}{c}}\right] T = -\frac{2\frac{v_n}{c}}{1-\left(\frac{v_n}{c}\right)^2}\, T. \tag{11}$$

Substituting the value of T in Eq. 11 we obtain:

$$D_t = -\frac{2\frac{v_n}{c}}{1-\left(\frac{v_n}{c}\right)^2}\,\frac{D}{v_n}\,. \tag{12}$$

For an early neutrino arrival time of δt with respect to the velocity of light we can write:

$$D_t = -\frac{2\frac{v_n}{c}}{1-\left(\frac{v_n}{c}\right)^2}\,\frac{D}{v_n} = \frac{D}{c} - \delta t. \tag{13}$$

Where $\frac{D}{c}$ is the light time arrival from CERN to Grand Sasso. Solving Eq. 13 for $\frac{v_n}{c}$ yields:

$$\frac{v_n}{c} = \sqrt{\frac{2}{1-\frac{c\delta t}{D}} - 1}\,. \tag{14}$$

Or,

$$\frac{v_n - c}{c} = \sqrt{\frac{2}{1-\frac{c\delta t}{D}} - 1} - 1. \tag{15}$$

Predictions

For the OPERA *corrected* result [2]

$$\delta t = \left(6.5 \pm 7.4\,(\text{stat.}) \begin{array}{c}+9.2\\-6.8\end{array}\,(\text{sys.})\right)\text{ns}$$

and $D = 730.085$ km. Substituting in Eq. 15 we get:

$$\frac{v_n - c}{c} = \sqrt{\frac{2}{1-\frac{299792.458 \times 6.5 \times 10^{-9}}{730.085}} - 1} - 1 \approx$$

$$\approx \mathbf{2.67 \times 10^{-6}}. \tag{16}$$

Which is identical to the reported result of:

$$\frac{v_n - c}{c}\,(\text{Exp.}) = \left(2.7 \pm 3.1\,(\text{stat.}) \begin{array}{c}+3.8\\-2.8\end{array}\,(\text{sys.})\right) \times 10^{-6}. \tag{17}$$

Equation 15 was also used to calculate theoretical predictions for the results reported by ICARUS [4] and MINOS [5]. The results are summarized in Table 1, which depicts all three experimental results against the corresponding theoretical predictions.

As could be seen in the table, *CR* yields accurate predictions for *all* three experimental results, *including the null ones*.

4 Concluding remarks

In this article I applied a recently proposed Complete Relativity Theory (CR) to analyze the neutrino travel in a typical neutrino-velocity experiment. CR treats all physical entities, including light velocity, as relativistic entities. Accordingly the measured velocity of light depends on the direction of the light propagation vector, relative to the laboratory. In terms of relative time, the start point laboratory (e.g., at CERN) will measure *time dilation*, whereas the end point laboratory (e.g., at Gran Sasso) will measure *time contraction*. It is important to note that the CR-based model presented in section 3 is independent of the particle type and its energy level. For the prediction of $\frac{v_n - c}{c}$ only the anticipation time δt and distance D between the start and end points are required [see Eq. 15].

The analysis brought above shows that CR predicts with near precision all the relative neutrino velocities $\frac{v_n - c}{c}$ obtained in recent neutrino-velocity experiments. In contrast, SR's predictions for all the discussed findings yields grossly incorrect results. What becomes clear from the analysis brought above is that a breakdown of Einstein's SR does not require that the neutrino velocity exceeds the velocity of light.

Upon the announcement of the first null result, the leader of ICARUS collaboration leader was quoted by the press saying that had they found 60 nanoseconds, he would have sent a bottle of champagne to OPERA, and that instead, he suspects that he "will be toasting Einstein" [31]. The analysis presented in the present paper suggests that the news about rescuing SR were premature, and that it makes more sense to keep the champagne in the frigidaire.

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